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ORIGINAL ARTICLES.

The Jordan Valley and Judean Highlands.

By Professor BAILEY WILLIS and Dr. LEO PICARD.

THE nature of the faulting which made the Jordan Valley and separated it from the Mediterranean by the Highlands of Judea has been discussed in a memoir by Professor Bailey Willis, "Dead Sea Problem: Rift Valley or Ramp Valley?" *Bull. Geol. Soc. Amer.*, xxxix, 1928, 490–542, and by Dr. L. Picard, *Geological Researches in the Judean Desert*, Jerusalem, 1931, 108 pp., 3 pl., and map.

Both authors further discuss the problems in the following papers.

I. FAULTS IN THE JUDEAN HIGHLANDS.

By Professor Bailey Willis.

The valuable contributions to the geology of Palestine—*Geological Researches in the Judean Desert* and *Tektonische Entwickelungsphasen im nördlichen Palästina*—by Dr. L. Picard show from the mass of facts he has recorded that he follows in the steps of his great forerunner, Dr. Blanckenhorn, and closely adheres to his reasoning regarding structural developments.

We are entirely in agreement in regard to the relative movements of the Judean plateau during the Upper Pliocene. The stratigraphic and physiographic evidence of uplift is quite convincing. That is, at least, a step toward a common interpretation of the causes of the displacement. The plateau has been raised with reference to sea-level, not merely relatively as contrasted with the Dead Sea trough.

Dr. Picard's *obiter dictum* that a theory of the faulting must stand or fall by the proof of the existence of the faults unfortunately does not hold if, as follows from the context in his statement (*Judean Desert*, pp. 93–4), the proof must be that of direct observation.

He says that "I could discover no visible evidence of the ramp-faults". It would be somewhat surprising if anyone had found the outcrop of the major ramp, which should emerge where the Palestine block rests against the Dead Sea block, deep beneath the waters of that sea. A ramp is a shear which originates in *deep-seated* rocks. If it curves upward and emerges at the surface it raises a mountain or plateau, whose escarpment is too steep to stand. The foot of the escarpment is immediately covered by land slides and these become of great volume if the upthrusting reaches great height, as is the case along the Dead Sea.

Similar slides would occur on the face of a rift-fault as on a ramp fault, and the direct evidence of faulting must in either case be obscured. Recognizing this inevitable condition, I concluded that: "The examination of the Dead Sea trough and its immediate environment on the west led to no definite conclusion, as to the origin of the displacements" (*The Dead Sea Problem*, B. W., 1928, 516).

The very obvious slides at the base of the cliffs that retreat from the Dead Sea were discussed by Rift and Ramp (op. cit., p. 513, where the theoretical structures are thus personified), without much satisfaction to either, but I am inclined to think that Ramp's explanation is strictly in accord with the evidence.

The next item which should logically engage attention is the "El-Muntar" fault. Dr. Picard has overlooked my references to it (op. cit., p. 517). If Mr. Geo. S. Blake, who pointed it out to me, named it, the name escaped me. I traced the fault, however, and satisfied myself that it is a feature of the flexure to which I gave the name Jericho flexure. As far back as 1873 Powell described the occurrence of a similar fault and its passage into a monoclinal fold (Powell, J. W., "Geological Structure of the Country North of the Grand Canyon of the Colorado," *Am. Jour. Sci.*, **3**, v, 1873, 459–6), and the relation is a common and logical one. The bending induces stretching and the stretching results in *normal* faulting. This being recognized, Dr. Picard and I are entirely in agreement as to the location of the El-Muntar fault, and we will agree to call it normal. But we do not necessarily mean the same thing by "normal".

A normal fault (as I use the term) is one which hades to the apparent downthrow (*Geologic Structures*, 1929, 67). One way in which such a fault may be produced is by gravity, which causes the downthrown block to sink with reference to the other. That I would distinguish as a gravity or rift-fault. The same effect, however, may be, and often is, produced by the upthrust of the upthrown block with reference to the other. The force involved is an anti-gravity force, which displaces the upthrust block and its foundations. The structure may indicate deep-seated ramping, and the fault itself might be described as a minor ramp.

Since we agree that the Palestine plateau has been raised, and since the El-Muntar fault is the kind of fault that ought to develop in consequence of the upthrusting, it would seem reasonable to Ramp that Rift should agree to that interpretation also.

It would be most gratifying if one could find conclusive evidence in the mere mechanical relations of faulting to answer those questions, but it is unfortunately true that any high-angle fault can be explained indifferently as a gravity slip or an upthrust and similarly any low-angle fault may be explained as an overthrust or underthrust, provided that it is considered by itself. Only when interpreted as part of a general movement can it be classed one way or the other. In the case of the El-Muntar fault the general movement of the plateau was one of uplift and the El-Muntar fault is an upthrust if it occurred during that movement.

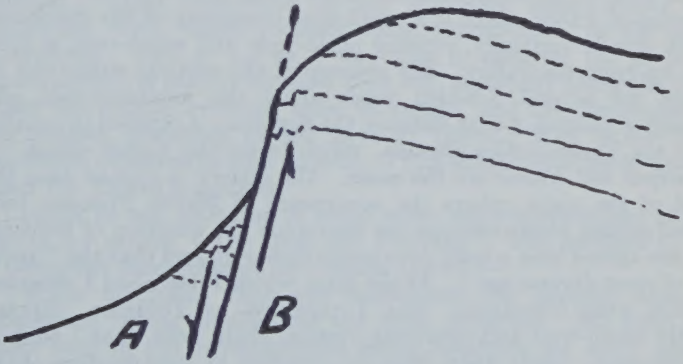

Fig. 1.—Fault of the El-Muntar Type.
Did *A* slip down or was *B* pushed up? Is it a Rift-fault or a Ramp-fault?

Turning now to the overthrust, upthrust, or gravity fault which traverses the escarpment of Mount Carmel above Haifa, there appears to be closer agreement between Dr. Picard and myself than the reader might gather from the statement of the case in his *Geol. Researches in the Judean Desert*, p. 94. I translate his description of the Carmel fault (*Entwickelungsphasen*, p. 173) :—

" The Carmel line, that is the fault along the north-east face of Mount Carmel above Haifa bay, goes back into the older Neogen, as most of the Erythraic faults do. It strikes N.N.W., as the Megido line does, and shows evidence of a peculiarly strong upward movement of the south-west block of Mount Carmel during the entire post-middle-Pliocene time."

Continuing the description, he refers to the marked disturbance of the strata : " There is here, as in Mount Gilboa, a general south-west dip of the strata and occasional marginal bending, accompanied by steeper dips and by stretching in the direction of the sunken basin, the plain of Haifa."

Our observations as to the general strike and dip agree closely, and we both noted evidence of disturbance which we attribute to faulting. Good.

Turning to *Researches in the Judean Desert* (p. 94), I quote further:

" The only real instances of ramp-faults occur, according to Willis, on the Carmel and at Gilboa. There, indeed, he considers it a case of overthrusts." " The occurrence at Jadpur is by no means certainly Upper Cretaceous; we have been able to demonstrate that even Middle Pliocene lies there, adjacent to chalk-like rocks. The rocks there, then, are of most diverse age, from Cretaceous to Upper Tertiary, which, like the same phenomena in the Rhine Valley, stand out as blocks at the edge of the mountains or in the plain."

My own statement of the relations which I observed was (*Dead Sea Problems*, p. 519): " Four miles from Haifa, at the cement quarries of Yabor, there is a small spur consisting of the Senonian, which stands vertically, striking north-west and south-east, a little way up from the valley. The outcrop of the vertical strata can be traced for several hundred yards along the mountain-side and through a portion of that distance the Senonian is exposed in contact with the Turonian-Cenomanian, which forms the higher slopes."

Jadpur and Yabor are the same. The quarry is opened near the level of the plain, where the occurrence of Middle Pliocene beds would neither excite surprise nor bear upon the question of faulting. We are agreed that a fault does occur higher up and that the " rocks are of most diverse age ". At the place which I described I observed certain hard limestones, that I regarded as Turonian, dipping gently south-west and overlying vertical chalk beds, that I took to be Senonian. Quite apart from the question of identification of the horizons, which the discovery of fossils in the beds in contact might prove to be other than I inferred from the characteristic lithology, the relations of the strata demonstrated the existence of a thrust fault. I regarded it as an overthrust, dipping about 30° to the south-west. It might possibly be an upthrust, a real minor ramp, and in that case could be interpreted by Rift as a vertical gravity fault, if one disregarded the fact that the fault " shows evidence of a peculiarly strong upward movement of the south-west block of Mount Carmel ".

Referring to the fault at Gilboa, which I took to be an overthrust because of the crushing of the strata at Herod's Well, Dr. Picard says (op. cit., p. 95): " In both cases, Gilboa as well as Carmel, we are dealing with faults, respectively faults accompanied by drag and bending of the strata at the boundary of the dislocation." I presume that Dr. Picard uses the word " fault " in this context to mean a normal fault, and with the interpretation of a gravity fault. I saw no reason to assume the occurrence of a fault of that type or of an upthrust, since the mountain slope is too gentle to suggest a fault scarp. I agree, however, that there is a fault along the base of the mountain, using the word " fault " to include thrusts.

I find a little difficulty in making that recognized faulting fit in with Dr. Picard's statement in the same paragraph that : " The strata themselves follow quite normally upon one another, with a slight pervading dip to the West." I can only infer that in the eagerness of controversy he has failed to describe with adequate precision the difference between the place where he recognized faulting and that where he observed normal sequence.

Again, citing my inference that Gilboa is a locality where " Lower Cretaceous is underlain by Upper Cretaceous ", he says : " Out of these strata I was able to identify indisputable Nummulites of the Eocene." Out of which strata ?

The occurrence of Eocene in the strata of the Besan plain would not be unexpected, but would have no negative bearing on the faulting. Their occurrence in the mountain slope, above the recognized fault, might indicate some complication in the zone of faulting. But so far as I was able to observe, the slope of Mount Gilboa is heavily covered with soil, especially along the base where the critical evidence must be sought, and the occurrence of the crushed limestone in the cave at Herod's Well is the only significant exposure in that vicinity. I find myself at a loss to understand Dr. Picard's account.

I regret to call attention to some other misinterpretations of the text of my article, " The Dead Sea Problem." For instance (p. 95 of *Geological Researches in the Judean Desert*) :—

" Willis maintains that our meridional and Somalic lines of disturbance belong to one and the same structure. We refer the reader here to our investigations which establish for each group of dislocations differences of age, different direction, and totally different manifestations of structure."

The question what constitutes a " system of structure " is one of usage. Conjugate joints, for instance, are commonly simultaneous. Chronologically they belong to one system, but since there are two series of parallel joints it might be said that they constitute two systems if classified by direction. Again, it is impossible to compress a body in one direction without extending it in another, unless there be volumetric change. The different effects of compression and tension may be classed arbitrarily as belonging to different systems, but they are, nevertheless, effects of a common cause, and a single episode. Or, again, it is well established that movements on folded or faulted structures have progressed during long periods or even been repeated many times with intervals of stability. Yet it is one structure. Thus differences of age, different direction, and different manifestations of structure may consistently be included in one and the same system. Sub-classifications and distinctive names are apt to be confusing and misleading.

I write of the system of structures in Palestine as one system because the different features are effects of related stresses, have had a fairly continuous development during the last few million years, occur within a geographical unit of rather small dimensions, and are probably due to a persistent cause.

On one fundamental point I must not fail to correct the impression (op. cit., p. 93)—" As to the causal aspect of the question how the Judean arch was uplifted, Willis assumes *magmatic forces* " (italics mine).

I have not been able to discover just where that misapprehension arose, but it piques my curiosity because it so sharply contradicts my firm opinion. I do not think " magmatic forces " could possibly have caused the uplift of the Judean arch, if the term be used in any sense consistent with the context in Dr. Picard's paper.

I understand magmatic force or forces to mean a force originating in the internal energy of the magma itself. I would distinguish it from a pressure originating in some condition extraneous to the magma but transmitted by the molten mass hydrostatically, after the manner of a hydraulic press.

Now, had Dr. Picard said: Willis thinks that magmatic forces, i.e. the internal heat and chemically active gases of a body of magma, situated at considerable depth beneath the eastern basin of the Mediterranean, stimulated the molecular forces of its cover and caused the solid rock to recrystallize in such a manner as to elongate horizontally and to push up the Judean arch; if he had said that I would not take exception to the statement.

It does not appear, however, that he had that theory of orogeny in mind. From the fact that he searched for extrusions of basalt in the Palestine arch (where I certainly would not expect to find them), I infer that he had in mind a laccolithic intrusion as the cause of uplift; at least, he attributed that idea to me. But it had never occurred to me and would be inconsistent with the mechanics of ramping in any case.

To sum up this quite inadequate discussion of Dr. Picard's interesting papers, it appears to me that :—

(1) We are agreed that the Palestine plateau was arched up during the Upper Pliocene. I would say the uplift is still in progress.

(2) We agree that the fault which bounds the Dead Sea trough along the base of the western escarpment cannot be seen. It may be either rift or ramp, so far as direct observation goes.

(3) We have both examined the El-Muntar fault, and agree that it is a *normal* fault, but he by implication classes it as a gravity fault, whereas I regard it as an upthrust.

(4) We have both observed the Carmel and Gilboa faults, and have noted the pronounced disturbance of the strata. He regards them as normal, gravity faults; I would not be surprised if they proved to be normal, upthrust faults, but I think the tilted uplift of Mount Carmel (which he also recognizes) favours the alternative

of a relatively low-angle overthrust, curving up to a steeper dip toward the surface.

(5) I am not surprised that some of the chalk is found to be younger than Upper Cretaceous, but I am unable to recognize the bearing of that fact upon the character of the faulting, since the exact relations of the beds in which the fossils are found to the older strata across the fault are not described. In any case, the strata cannot "follow quite normally upon one another" where the marked disturbance of the rocks has led both of us to recognize faulting.

(6) The question of the term "system" in connection with a group of structures is one which we interpret differently, but we recognize the same sequence of events. Dr. Picard lays more stress upon details than I do in describing the movements. Ever since the days of Élie de Beaumont geologists have been prone to set up artificial groupings, as in the case of parallel structures, for instance, even though Suess demonstrated the continuity of winding directrices.

(7) As regards the original cause of the uplift of the Judean arch and related structures including the Dead Sea trough, Dr. Picard appears to have misunderstood my views. I, at least, do not recognize them as stated or implied by his text.

II. THE HYPOTHETICAL RAMP-FAULTS IN PALESTINE.

By Dr. L. Picard, Department of Geology, University of Jerusalem.

I have read with pleasure Professor Bailey Willis' interesting paper, and refer to his comments in the same order.

How far I agree or disagree with older authors is, I hope, sufficiently indicated in my paper. I am glad to see that Blanckenhorn, who for many years was a strong holder of the pure "horst" theory of the Judean mountains, now also believes in their anticlinal structure.

It would appear that Professor Bailey Willis is of opinion that I did not understand the meaning of his ramp-fault, but I cannot discover that my explanation of ramp-faults on p. 93 differs much from his, and his figures and demonstrations are so lucid that even a beginner in tectonic study must understand them.

I fully appreciate his argument that direct observation of ramp-faults is difficult if not often impossible. For those geologists, however, who reside in Palestine and who have to deal, like myself in the last seven years, with its tectonic problems, it is important to work on such theories or hypotheses for which proof will be possible sooner or later. Professor Willis says that a ramp-fault and the direct evidence of faulting must in a certain case be obscured, and refers to the Dead Sea trough. But I ask, why should the whole zone of cliffs with its splendid outcrops between Ras-es-Feskha and

En-Gedi on the West or between Zerka Main and Arnon, W. Mojib), on the East, with several thousand feet of throw, be insusceptible of direct ramp observations, while Carmel and Gilboa with less throw provide good material for the direct observation of upthrusting? The rocks of Carmel and Gilboa are at their deepest outcrops between sea-level and – 80 m.; but the rocks of the Dead Sea can be observed down to – 400 m., the latter region presenting its well-known and remarkable incision on the surface of the earth.

In contrast to Professor Willis' pessimistic conclusion—" The examination of the Dead Sea trough and its immediate environment on the west led to no definite conclusion as to the origin of the displacements "—I believe, that if any solution of the rift problems can be obtained the investigation of the Dead Sea depression will play an important part.

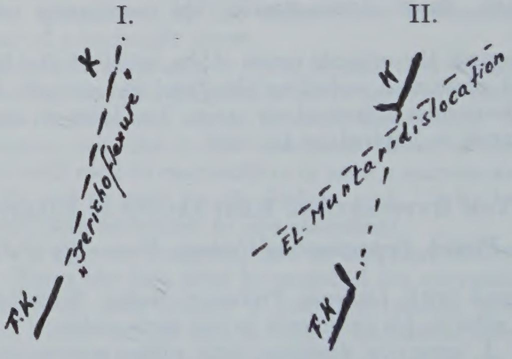

Fig. 2.—The Jericho flexure and the El-Muntar fault.

I = Professor Willis' Jericho flexure.
F.K. = position of Feshka-kumran crescentic fault.
II = my El-Muntar dislocation.
K. = position of Kuruntul fault.

With regard to the El-Muntar fault, which was determined by Blanckenhorn (1896) as a flexure, and which Professor Willis thought identical with his Jericho flexure, I had not overlooked his description on pp. 516, 517. Unfortunately, however, he brought together both structure-lines—that of the Dead Sea fault and Jericho flexure identified by him with the El-Muntar fault so " that the first is replaced by the latter ".[1] He regards other monoclinal faults as similar; e.g. he says of the Es-Salt line: " The cliff retreats and becomes a flexure "; and of the Damascus line (p. 527): that " it died out in a monoclinal flexure, as is so often the case with similar thrust-faults ". But the best proof that he had in mind one and the same structural line is to be observed from his map. There the so-called Jericho flexure rises out from the Dead Sea cliffs and passes into the Kuruntul fault, thus combining both the crescentic faults.

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[1] There seems to be some confusion here, since my map shows the fault to which I refer as quite distinct and further up the slope.—B. W., January, 1932.

The sketch above shows clearly that Professor Willis' Jericho flexure has a quite different direction and appearance in contrast to my El-Muntar fault.

Professor Willis' figure, which explains how one part of a monoclinal fault has slipped down or vice versa has pushed up, can easily be transferred to my section AB of the geological map. But we can only observe that the west part of the El-Muntar dislocation (e.g. Professor Willis' block B) always shows a strong puckering of the strata, indicating, therefore, dragging and down-warping of the strata *in* the direction of the trough-valley.

Howsoever we regard the El-Muntar flexure or fault (I myself called it a very big shear—or shift—fissure, see p. 84), it belongs to the series of Somalic (N.N.E.) lines which, as often pointed out, differ totally in structure from the big crescentic faults. The latter bordering the Dead Sea belong to the system of the meridional main rift-faults.

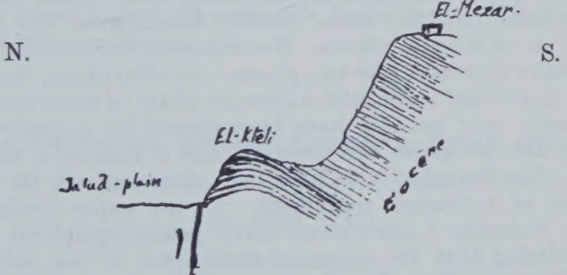

Fig. 3.—Section of Jebel-El-Kleli.

Carmel and Gilboa are the part of the country in which Professor Willis claims to have found evidence of ramp-faults. As regards their structures, I refer to my sections of the geological maps (*Kischonebene,* Haifa map 1928, *Besanebene* 1929). I am sorry to say again that—in spite of a thorough survey—I could not observe upthrusting or overthrusting. My map of Jadpur and description (1928) give enough details to explain my interpretation of the border of Mount Carmel at that place. I repeat that the blocks bordering the fault-line do not consist only of disturbed Cretaceous, but are mainly Pliocene. As regards Professor Willis' explanations, I cannot imagine how the Pliocene has been upthrust or overthrust by the older Cenomanian. I fully appreciate that an upthrust is not an overthrust. (See my remarks on p. 94.) I followed Professor Willis' own description of fig. 1, which bears the title " Overthrust ", and pp. 518, 519, where he speaks further of " overthrusting " or " overthrust " in the Carmel; and p. 520, where he wrote with regard to Carmel and Gilboa: " The outcrop . . . indicates a high-angle *upthrust fault* or ramp."

With regard to Gilboa, I could not in my recent paper go into much detail and repeat all the facts described or figured already in my *Geologie der Besanebene* (1929)—to which the reader is referred. Professor Willis asks: " Out of which strata are the Nummulites ? " The reply is: from the strata which he figured in his fig. 1, plate 18 (*Dead Sea Problem*, 1928). This mountain is called Jebel-El-Kleli. To avoid misunderstanding I give again a sketch of the locality.

On the ascent of El-Mezar the strata are seen to follow normally one upon the other. The nummulites are distinctly Middle Eocene of Mokattam character.

With regard to the questions of chronology of structure-lines: There was no doubt in my mind that north–south main (border) faults were not originated by a single action; and I mentioned also in my paper that earthquakes along these faults, especially along Somalic (N.N.E.) lines, clearly demonstrate the existing continuation of the movements. Nevertheless, the crescentic faults which I have separated into two phases—an older phase, the north–south or meridional faults, and a younger phase or transverse faults (45 degrees)—may possibly have been formed by a single action. I am not able to decide this question, and it remains a matter of opinion. The Somalic or N.N.E. lines, however, are for me the expression of a younger movement. In my paper dealing with Northern Palestine I have given many paleogeographical reasons for considering that the origin of these lines is not older than Upper Pliocene. This N.N.E. direction is, because young, the best preserved and most striking tectonic feature not only in Palestine, but also in Syria; and it is certainly connected with the latest orogenic movement of the Mediterranean mountain chains.

These reflections bring me to the last point: the causes of the upwarping of the Judean arch and the causes for the origin of the trough. I understood by " magmatic forces " what Professor Willis describes on p. 6 of his paper as " the internal heat and chemically active gases of a body of magma, etc., etc." I am therefore grateful to him for his correction of an expression which may have given a wrong impression to the reader. Nevertheless, regarding the tectonic causes, I repeat, as I remarked in my memoir, that the cause of the uplift is not here (i.e. in my paper) investigated: " A solution cannot be attempted until we are quite clear about the structural manifestations."

Summarizing the discussion:—

To solve the question of Professor Willis' theory—that in the structure of Palestine ramp-faults play an important part, the main point, namely the existence of ramp-faults, still remains unproved in Palestine. I am sorry to have to abide by my conclusion on p. 105 of my book that there is " no certain evidence of ramp-faults."

My reasons are :—

(1) The Dead Sea faults give, according to his own words, no definite conclusion.

(2) The Mount Carmel upthrust-fault or overthrust as the case may be, is stratigraphically unproved. Also a thorough survey of that region indicates tectonics quite different from those characteristic of " ramp-faults ".

(3) The Gilboa north-west border has for the same reason as in (2) no ramp character. A totally normal succession of the strata from the very beginning at the foot up to the top of the mountain can be observed. There are no outcrops of older rock (Cenomanian-Turonian, Lower Cretaceous). For points (2) and (3) I again refer to my description and geological maps of Carmel and Gilboa (1928–9).

With regard to the different origin in time of the dislocations I believe strongly that the crescentic faults are of older, the Somalic lines of younger, origin.

The Ballantrae Igneous Complex, South Ayrshire.

By D. BALSILLIE, F.G.S., Royal Scottish Museum.

(PLATES V–VII.)

INTRODUCTORY.

IN the early days of the Geological Survey of Scotland, the rocks of the Ballantrae Igneous Complex were thought to be of metamorphic origin. Thus in the memoir explanatory of sheet 7, scale 1 inch = 1 mile, published in 1869, it is stated that the chief interest attaching to the altered strata of this district consists in the fact that they exhibit certain arrested stages of metamorphic action. But less than ten years after that date the erroneous character of this opinion was made abundantly clear by Professor Bonney. Equipped with experience gleaned in the Lizard, Bonney quickly recognized in Ayrshire a correspondence in the nature of the phenomena. Excellent descriptions were furnished by him of some of the lavas, serpentines, and gabbros, and their true igneous character emphasized.[1]

Lapworth's discovery of a Middle Arenig fauna in shales associated with volcanic ash, exposed upon the shore under the Bennane Head, was the next important advance in knowledge of the Ballantrae rocks. Thereafter progress became more rapid. Drs. Peach and Horne, adopting the brilliant zonal results achieved by Lapworth in the Moffat and Girvan areas, began their great revision of the stratigraphy of the Southern Uplands. In the course of this work they remapped large sections of sheet 7 and, where thought to be necessary, they submitted to Sir Jethro Teall specimens of the rocks collected for petrographic examination. The descriptions of that petrographer are carefully given in the memoir on *The Silurian Rocks of Britain*, I, Scotland, 1899. Some of Teall's conclusions, it may be stated, had two years previously been presented by Sir Archibald Geikie, in an interesting account of the Ballantrae rocks that appeared in *Ancient Volcanoes of Great Britain*.

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[1] " On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast," *Quart. Jour. Geol. Soc.*, xxxiv, 1878, 769.

The following notes have been assembled as the result of several years' intermittent holiday hammering in the Girvan and Ballantrae areas, and it is hoped they will be found in some measure to extend the information already available in the great work of Peach and Horne. It has not been possible, within such stringent limitations of space as are here prescribed, to refer to every rock type occurring. Therefore in this paper will be found only a sketch of the petrography of the main rock groups that build the region.

LAVAS.

The effusive rocks of the Ballantrae region were classed by Sir Jethro Teall as diabases and diabase-porphyrites. Both types are generally so much altered that it is difficult to collect in the field satisfactory material for petrographic examination. But, indeed, the weathered or apparently weathered condition of these old lavas is one of their characteristic features. Thus Mr. Dewey and Sir John Flett, in their paper on " British Pillow-lavas and the Rocks associated with them " (GEOL. MAG., 1911), state that " in addition to the pillow-structure there are certain characteristics that mark the spilites of Great Britain. The first of these is that they are as a rule very completely decomposed ". The spilitic facies of the South Scottish Arenig province was, of course, definitely recognized by Dewey and Flett, although it must be stated that Teall did not fail to correlate, on chemical, textural, and mineralogic grounds, the pillow-form rocks with the well-known spheroidal basalt from Point Bonita, on the north side of the Golden Gate, California, described by Dr. F. L. Ransome.[1]

It would be unnecessary here to digress into any review of the field characters of the spilites of the Ballantrae area. The correspondence with familiar examples described from many parts of the world seems to be very close. Perhaps the best available exposures exhibiting the ellipsoidal structure are at Downan Point, a little south of Ballantrae village, and a locality on the coast somewhat less than a mile still further south, where the display is indeed

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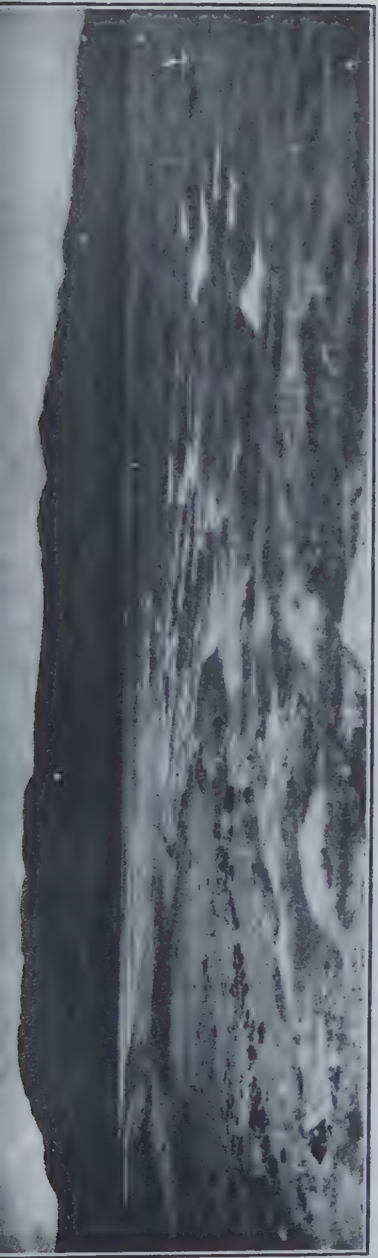
[1] *Bull. Geol. Dept. Univ. California*, i, 1893, No. 3.



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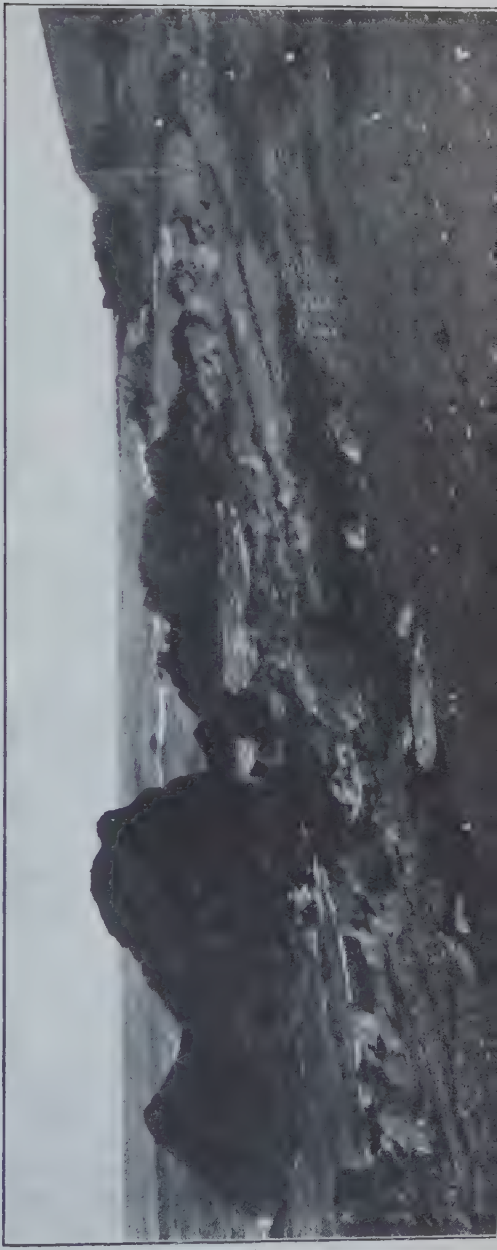

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Fig. 1.—The Girvan-Ballantrae Hills.
Fig. 2.—Albite-diabase Intrusions, near Lendalfoot.

[*To face p.* 108.

magnificent, the disposition of the pillows with their vesicular zones showing clearly how the rocks have been tilted on end and sometimes even inverted.

Microscopically examined, average examples of the fine-textured non-porphyritic types are found to consist essentially of long, thin, curving microlites of felspar, which may have no definite orientation, or may be disposed in fluxional arrangement (microphotographs illustrating characteristic structures are reproduced in Pl. VI, Figs. 1–3). Of distinctly later crystallization than the felspar is monoclinic pyroxene, often purple and showing inclined dispersion. Quite a common feature is a curious pectiniform disposition of little pyroxene crystals along the sides of the felspar microlites. Where the texture becomes coarser the pyroxenes may be fascicled or bunched and then grow branch-like, enclosing and enmeshing the felspars. Iron ores and glass fill the interspaces. The vitreous matter can often be seen gathered into vesicles that must have dilated after the rocks had ceased movement, the felspar crystals being then arranged in tangential manner around the cavities. In few cases is the glass of the rocks unaltered, nearly always it is devitrified, or replaced by chlorite and calcite. But sometimes, as noted below, it is preserved with remarkable freshness. The phenomenon of albitization is one of widespread occurrence among these rocks, and the various mineral reconstructions that accompany the substitution of soda-felspar for lime-bearing plagioclase are frequently displayed with great clearness. Albite, chlorite, calcite, prehnite, epidote, zoisite, and pectolite appear here, as elsewhere, among the products of change. Some of the rocks are puzzling. Thus in the fields east of the road to Currarie farm, south from Ballantrae, excellent pillow-lavas are exposed where it is possible to collect rocks that show apparently quite fresh albite and pyroxene. And again near the summit of Carleton Hill, at Lendalfoot, rocks may be obtained in which the pellucid nature of the felspar seems at first to indicate a primary origin. It may, however, safely be stated that in no instance is the bulk of this mineral other than a replacement or inversion product. A citation of all the evidence sanctioning that opinion is not immediately proposed. It may suffice to state that some of the rocks carry both felspars, thus exhibiting a partially albitized phase. The character of the secondary felspar is curious. It has a slightly warmer tint in the microscope field, is generally crowded with finely-divided secondary products, and is obviously of a lower refringence. Some of the rocks subsequent to albitization have had the albite replaced by analcite. Albite veins, analcite veins, prehnite and calcite veins, are all of common occurrence in these Ballantrae spilites, and these substances along with quartz are found, too, in the vesicles. But frequently the vesicles are empty, and are then usually coated with a chocolate brown interior crust that furnishes a valuable clue to the identification of the rocks in the field.

A widely observed character among the Ballantrae spilites is a sub-variolitic structure, which is conferred by a stellate, or sub-stellate, grouping of the felspar crystals. And the iron content of the rocks seems occasionally to be very high, certain types that occur as disrupted blocks in the great agglomerate at Bennane Head approximating in this respect to the magnetite-keratophyres described by Benson[1] from New South Wales.

The porphyritic types are admirably exemplified by the masses exposed on the coast at Port Vad and Stockenray Bay, or inland at Knockdolian and on the hill-top north of Barchlewan, in the valley of the Lendal Water. These rocks are sometimes doleritic in texture, but many show clearly their affinity with the non-porphyritic types in the character of their ground mass and in the curious bunching of the pyroxenes above noted. Some of the best examples illustrating the characters of the porphyritic lavas can be collected on the shore at the south end of Stockenray Bay, just below the road and to the south of the ash or agglomerate immediately to be referred to.

The habit of the porphyritic rocks now exposed at the north and south ends of Stockenray Bay is deserving of careful study. For between these distinctly crystalline masses there lies, in the centre of the bay, a remarkable ash or agglomerate, crowded with rounded blocks of a porphyritic rock of identical habit but having a ground dark and resinous. Teall[2] described these blocks as consisting of "porphyritic tachylyte", which indeed is a very good and concise statement of their character. Unfortunately the field relations of the exposure have not been clearly determined. Obviously on the south side of the bay the rock is faulted, with an intervening dyke, against the crystalline porphyrite, which is here underlain by ash and overlain by non-porphyritic spilite. But the available evidence should in any case not be misinterpreted. The blocks out of the ash when sectioned reveal a beautiful glassy porphyrite (see Pl. VI, Fig. 4). Now the shape and disposition of the felspar microlites, as well as the crystalline grouping of the purple titaniferous pyroxenes, associate this rock unmistakably with the typical diabase-porphyrites above referred to. The remarkable feature is, however, that all the felspars consist of quite unaltered labradorite of a mean refringence 1·562 and corresponding to a composition $Ab_{35}An_{65}$. Either for the reason that the blocks have been sealed up in an ash deposit, or because they consisted in large part of impervious dense glass, they appear to have escaped the processes that spilitized or albitized the great province. The results of a chemical analysis of the porphyritic tachylite, which I now designate pre-spilite, are given below and therewith are ranged the corresponding details of one of the Hawaiian felspathic basalts.

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[1] *Proc. Linn. Soc. N.S. Wales*, xliii, 1918, 372.

[2] *Sil. Mem.*, 445.

	I.	II.
SiO_2	47·01	49·01
Al_2O_3	18·07	16·29
Fe_2O_3	5·15	7·61
FeO	5·20	4·89
MgO	3·17	3·62
CaO	10·00	9·79
Na_2O	3·46	3·82
K_2O	0·63	·80
$H_2O > 105°$	1·11	—
$H_2O < 105°$	2·38	—
TiO_2	2·94	3·93
P_2O_5	0·45	0·49
MnO	0·10	0·27
CO_2	0·16	0·32 ($SO_3 + S + CuO$)
FeS_2	0·14	—
	99·97	100·84

I: Lava block, in agglomerate, Stockenray Bay, 1¼ miles N. of Lendalfoot (analysed by B. E. Dixon).

II: Porphyritic basalt, Kohala Mountain, northern district of Hawaii (analysed by A. B. Lyons). Ref. *Washington's Tables*, 1916, 522.

The evidence furnished by the Stockenray rock cannot, I think, lightly be set aside, but on the other hand it seems to afford convincing proof that the spilites must have resulted from some process of hydrothermal metamorphism or metasomatosis. At the north end of Stockenray Bay a normal diabase-porphyrite occurs, which exhibits a comparatively unaltered basic phase, and also one in which the felspars have been completely replaced by albite and translucent analcite.

In order to gain further information concerning the lava types of the Ballantrae province, many of the blocks enclosed in the various ashes and agglomerates have been sectioned. From the ash at Lochton, about one and a half miles due south of Lendalfoot, a number of disrupted fragments of spilite were taken which vividly recall a rock that occurs at Tregidden in the Lizard. The latter contains primary oligoclase or andesine and carries abundant ophitically related purple augite. The Lochton rocks correspond closely but are generally in rather an altered condition, the felspars being largely replaced by prehnite. One exceptional type was a beautiful sub-variolitic spilite in which the microlites were set in a base of devitrifying pale brown glass.

In the ash or agglomerate at Bennane Head a number of interesting rocks are found. Some of these are albitized andesites carrying phenocrysts of pale green, or colourless, diopside in a ground of secondary albite. Flow-structure may or may not be developed in these masses and the content of magnetite is often considerable, increasing sometimes to such an amount that the rocks correspond, as noted above, to magnetite-keratophyres. It should be observed that some of the disrupted rocks microscopically approximate to oligoclasic basalts in composition and carry primary fairly acid plagioclase.

On the roadside at the south end of Stockenray Bay an ash is exposed which was remarked by Drs. Peach and Horne to contain blocks of a pink, fine-grained felsitic rock, apparently more acid than any of the diabase lavas. These have been ascertained to be porphyritic albite-trachytes and albitized andesites. Rocks of the latter type also occur in the ash of Mains Hill, east from Ballantrae. Nearly always these andesites carry phenocrysts of pale green, or colourless diopsidic pyroxene, which, although the body of the rock is generally considerably altered, remains in a surprisingly fresh state.

SERPENTINE AND ASSOCIATED ULTRA-BASIC ROCKS.

It is not intended in the present paper to make detailed reference to the Ballantrae serpentine. Much of the country underlain by this great component of the igneous complex is pasture-clad moor and all the available exposures require further careful examination. But it may with confidence be stated that, as far as they go, Bonney's descriptions, after fifty years, are not yet in serious degree out of date. They have been quoted in the Upland Memoir and it is not difficult to-day to verify their substantial accuracy. Easily the most abundant variety of serpentine in South Ayrshire is bastite- or lherzolite-serpentine, which seems to be of widespread occurrence. Dunite and tremolite-bearing serpentines are found at various localities but any regional distribution of these types has not been made out. The serpentine exposed at the head of Poundland Burn is an altered dunite carrying abundant brown picotite, that mineral also occurring, as previously described from this locality, in segregations and veins. As stations where typical specimens of the bastite-serpentine can be collected there may be mentioned the quarry upon the south slope of Balhamie Hill, a short distance west of Colmonell, and a group of natural exposures near the site of old Knockdolian Castle, nearly a mile further west. The details of an analysis recently made from the rock of Balhamie are given on p. 113. Therewith are placed the particulars of two other analyses, the explanations being subjoined.

That the ultra-basic rocks of the region form a banded complex seems fairly clear. Thus ranging north-east from the headwaters of the Poundland Burn and along the north face of the Breaker Hill is an extensive belt of picrite. Specimens collected from this zone about one mile north-west from Daljarrock were reported upon by Teall,[1] who stated that the rock possessed decided affinities with the hornblende-picrite described by Professor Bonney from Penarfynydd in the Lleyn peninsula, Carnarvonshire, and that it resembled certain banded rocks which occurred at the Lizard in intimate association with the serpentine. Teall's description, however, does not seem generally applicable. The rock consists in the best exposures of

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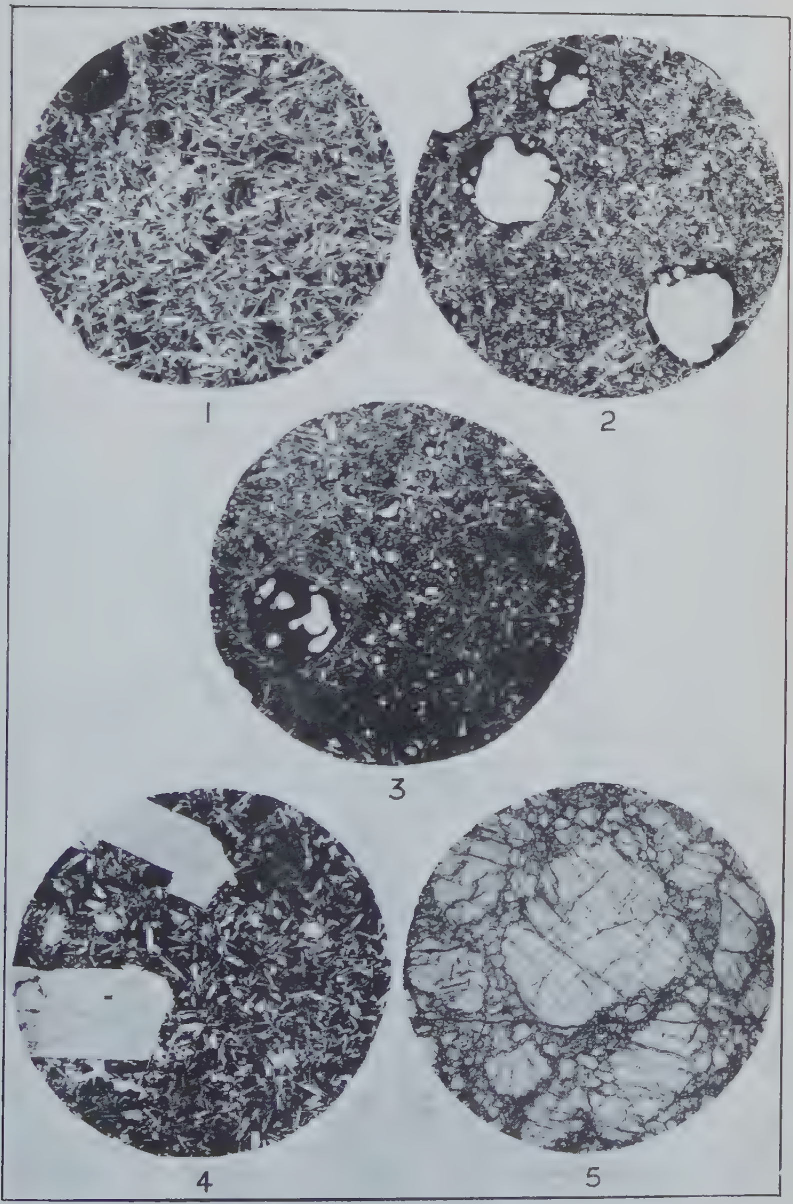
[1] *Sil. Mem.*, 469.



ARENIG IGNEOUS ROCKS OF THE BALLANTRAE REGION.

[*To face p.* 112.

large plates of clear or turbid, pale brown or colourless, much fissured, schillered and sometimes diallagic, monoclinic pyroxene, enclosing sub-idiomorphic and rounded crystals of olivine now partly altered to serpentine. The pyroxene is changing to hornblende, which shows a beautiful pleochroism in shades of sepia brown and pale ochre. A brilliant orange-red biotite occurs conspicuously in many specimens. This belt, which is found to be of much wider extent than indicated in the Memoir, varies in its character from place to place. Olivine is always the dominant constituent but sometimes, as just noted, specimens exhibit a striking content of pyroxene, which in others becomes wholly replaced by hornblende. In the field the picrite shows a distinct lustre-mottling and is marked by pale green or white strings or patches, that may coalesce to form a reticulum that contrasts strikingly with the ground of the rock. Teall thought that the pale substance resulted from the alteration of some soda-lime felspar. This, however, seems to be a wrong conclusion, as the examination of many sections shows that it is the ferromagnesian silicates that are in process of replacement. Especially can the successive stages of the substitution be ascertained from a study of the hornblende. Bars of ilmenite, or titaniferous magnetite, are first deposited along the cleavage traces of that substance and the body of the mineral thereafter disappears and is

	I.	II.	III.
SiO_2	38·58	40·04	38·29
Al_2O_3	1·65	0·40	3·95
Fe_2O_3	3·94	5·77	2·53
FeO	2·49	1·91	4·04
MgO	37·84	37·26	35·55
CaO	0·04	—	0·57
Na_2O	0·62	—	—
K_2O	0·11	0·60	—
$H_2O > 105°$	12·68	13·42	14·08
$H_2O < 105°$	1·49	—	—
TiO_2	0·04	—	—
P_2O_5	0·04	—	—
MnO	—	—	—
CO_2	0·10	—	—
FeS_2	0·10	—	—
Cr_2O_3	0·24	0·39	—
NiO	0·06	—	0·15
	100·02	99·79	99·16

I : Bastite-serpentine, quarry upon south slope of Balhamie Hill, west of Colmonell (analysed by B. E. Dixon).

II : Serpentine, Byne Hill Burn (analysed by Philip Holland). Ref. Mellard Reade, *Proc. Liv. Geol. Soc.*, viii, 1900, 109.

III : Bastite-serpentine, Balhamie, near Colmonell, "from a pit near the roadside, about three-quarters of a mile from the village" (analysed by F. T. S. Houghton). Ref. Bonney, *Quart. Jour. Geol. Soc.*, xxxiv, 1878, 771. This analysis has been prepared from material dried at 100° C.

replaced by a very pale or nearly white chlorite. The iron ore then alters to granular leucoxene, which retains a high index of refraction and strong birefringence. Subsequent change then affects the granules, they seem to become quite translucent and often coalesce. Their index of refraction sinks to about the value 1·728 and they become isotropic. The identity of this leucoxenic end product, which looks like some variety of garnet, has not been ascertained.

Reference to the 1-inch map will show that the picrite zone just noted lies along the southern margin of the belt of serpentine stretching from Drummore Shore to Millenderdale. It is deserving of mention that in the northerly tract of serpentine, ranging from Lendalfoot to Byne Hill, some further interesting rocks have been found. The boundary of the serpentine, here skirting the north-west flank of Carleton Hill and striking obliquely across the trend of the Lendal Water, is evidently, as noted by Drs. Peach and Horne, a line of considerable movement, for marked dynamic effects have been produced. Rocks of an intense schistosity can be seen high on the steep face of Carleton Hill, and at several places along the line of the Lendal Water the effects of powerful deformation are visible. Some of the best exposures of the crushed and deformed materials have been laid bare by the tributary streams coming in upon the north side of the valley, about three miles inland from the coast. One of the flasered masses, about 600 yards north-west of Laigh Knocklauch, was noted by Teall (*Sil. Mem.*, 458) to carry garnet, and other outcrops of a sheared and altered gabbro-diorite, carrying abundant porphyroblasts of pink garnet, framed in reaction rims of green actinolite, have been found by me about the same distance due west of the farm, and again somewhat less than a mile to the north of it, in the stream behind the ruin of Lochton Cottage. At the latter locality the garnetiferous schist abuts against tremolite rock that has been produced by the dynamic metamorphism of the contiguous serpentine. It is not, however, to this belt of crushed and deformed rocks that it is now intended to refer, but to a curious group of interbanded pyroxenites, bronzitites, and serpentinous schists, that emerge upon the higher hill slopes a short distance west of Knocklauch. The pyroxenites are of doleritic texture, pale green in colour, beautifully fresh, and in thin section manifest slightly the effects of pressure. Sometimes the structure is an even hypidiomorphic one, but in the majority of sections a rude porphyritic structure is observable (see Pl. VI, Fig. 5), large crystals of schillered and often diallagic, colourless or pale green, diopside lying in a somewhat granular ground of the same substance, or one that may consist of diopside and bronzite, or perhaps wholly of bronzite. The bronzitites have quite a corresponding structure, larger, slightly distorted, unaltered individuals of orthorhombic pyroxene occurring in a base of granular bronzite. In the stone fence, a few yards to the west of the outcrops of garnetiferous rock first above referred to, a number of large blocks of bronzitite may be seen the crystals of which measure up to an inch and a half in length, and microscopically build a mesh of typical hypidiomorphic habit (see Pl. VII, Fig. 1). Evidently there are considerable intercalations of this material in the banded serpentines and pyroxenites at this part although I have not yet succeeded in locating them in the field. The bronzite of the above rocks, it may be added, has indices of refraction between 1·66 and 1·68 and an axial angle $2V = 86°$.

Over a great extent of the moor to the north, north-east, and north-west of the pyroxenites a distinct foliation and mineral banding can be detected in the serpentine. This parallel structure, the plane-traces of which strike nearly along a line joining Millenderdale farm to the summit of Grey Hill, has nothing whatever to do with the line of movement along the Lendal Water. Especially to advantage can the foliation be studied at some exposures about a hundred and thirty yards to the south-east of the cairn on the hill-top west of Laigh Knocklauch, where the structure planes dip at a high angle to the west and where the rock consists of olivine- and pyroxene-rich bands. The diopsidic zones vary from mere threads or strings up to courses about an inch and a half in cross measurement, and a piece of rock no more than a foot in thickness may show as many as thirty or forty quite regular belts. Where the rock becomes more massive the foliation yet persists as a marked feature, and can be discerned to result from a parallel orientation of the bronzite and diallage cleavage planes. A wide variety of types can be collected here—imperfectly serpentinized harzburgites, lherzolites, olivine-tremolite-bronzite-diallage rocks, and sometimes beautiful olivine-tremolite-ceylonite schists that recall strikingly certain banded varieties of the tremolite-serpentine, exposed in shallow roadside pits near Traboe Cross, in the Lizard. All the foregoing petrological varieties, it may be pointed out, seem to agree closely with rocks that have lately been reported upon by Dr. Wagner from the Rustenburg District of the Transvaal.[1]

GABBROS.

One of the most interesting unfoliated gabbros in the Girvan-Ballantrae district is that exposed on the left bank of a watercourse half a mile east of Ardmillan House. This rock is of average gabbroic texture and in a hand specimen shows fine lustre-mottling. Microscopically it might quite well be described as an ophitic hornblende dolerite (see Pl. VII, Fig. 2). The mesh of plagioclase (60% An.) felspar crystals of which the rock is composed is often open to the extent of allowing the mineral to carry idiomorphic contours. Binding the whole together are large plates of pleochroic deep red-brown hornblende enclosing abundant ilmenite. The hornblende is quite fresh and has every appearance of being a primary product of crystallization. Nevertheless, its secondary character is not beyond doubt as it is often associated or intergrown with a colourless, schillered, monoclinic pyroxene.

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[1] *On Magmatic Nickel Deposits of the Bushveld Complex in the Rustenburg District, Transvaal,* Union of South Africa Geological Survey, Mem. No. 21, 1924.

Not far to the north of the locality referred to lies Mains Hill, which is built of unfoliated hornblende-gabbro. Microscopically the rock much resembles the above, but the hornblende is green and the felspars are saussuritized, the saussurite consisting of turbid albite full of secondary products and associated with prehnite. Colourless pyroxene likewise occurs here in association with the hornblende.

Other good ophitic gabbros occur at Byne Hill and at the east end of the Daldowie Hill igneous inlier. At the former locality the rock carries hornblende and diallage. From the east side of Byne Hill, and near the junction with the serpentine, an olivine-bearing ophitic type has been described by Teall.[1] And at the same time he gives an interesting account of the passage to quartz-dolerite, diorite, and granite, as the hill slope is ascended. The whole ridge that here trends south-west is evidently a composite intrusion, the magmatic phase introduced last being of thoroughly acid character.

It is difficult to distinguish the normal gabbros of the Ballantrae region from those that have been modified in some manner by pressure. One of the intrusions that it is proposed to refer to here, although the rock has manifestly experienced slight deformation, is that occurring on the foreshore a short distance to the north of the sixth milestone from Girvan, on the Girvan-Ballantrae road. This mass I designate Bonney's Dyke, as it was here that Professor Bonney obtained the material upon which some of his descriptions are founded. The rock is an ophitic diallage-gabbro generally much altered and with the pyroxenes uralitized, and the felspars replaced by opaque white prehnite and pectolite. This rock certainly has contained an orthorhombic pyroxene as some sections show that mineral delicately pleochroic in shades of palest pink and green.

Not many yards to the north of Bonney's Dyke another mass is seen, near low water, which is a beautiful norite, consisting almost entirely of quite fresh euhedral colourless enstatite crystals that are enclosed in large plates of basic plagioclase.

A good deal of interesting information can be gathered at this part of the coast. The fact of the later date of the gabbro can easily be confirmed. But the younger rock is not chilled, although flasered along part of the margin. It encloses fragments of the bastite-serpentine, as well as of the diallagite-pegmatites that are here seen in such splendid display. Another matter deserving of study is the curious manner in which some of the saussuritized gabbro surfaces yield to the attacks of the weather. The ferromagnesian constituent of the rock being more easily removed than the saussurite leaves a green pitted and corroded exterior that consists in large part of prehnite.

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[1] *Sil. Mem.*, 482.

Some of the gabbroic rocks of the Ballantrae region contain remarkably little ferromagnesian ingredient and then pass over into (albitized) anorthosites. The felspar of these rocks is often thoroughly acid plagioclase. Excellent examples in the district may be cited from the south end of Fell Hill (1,300 yards south-east of Ardwell) and from the flanks of Knockdaw Hill, near Millenderdale. They consist of albite that is nearly always crowded with granules of secondary products. The Knockdaw rock shows little or no parallelism of its felspar crystals, but is traversed by many minute fractures, and some slides show each large felspar individual surrounded by granular albite and often the crystals are broken and repaired by the same substance. The Fell Hill anorthosite shows a rude parallelism of its albite felspars but is not granulitized. The most interesting feature of the latter mass is the beautiful specimens that may be collected showing the replacement of the felspars by prehnite and pectolite. The Knockdaw rock carries an appreciable amount of sphene, but little or no apatite is found in either. An analysis of the Fell Hill white gabbro yielded the results given below. As will be seen from the comparisons provided, the rock petrographically is an albitite or plagiaplite.

	I.	II.	III.
SiO_2	56·31	59·71	59·48
Al_2O_3	22·70	25·47	24·10
Fe_2O_3	0·09	0·17	0·66
FeO	1·16	0·22	—
MgO	0·54	—	0·39
CaO	9·89	8·24	8·21
Na_2O	6·33	5·48	6·67
K_2O	0·75	0·22	0·49
$H_2O > 105°$	1·70	0·86	—
$H_2O < 105°$	0·14	—	—
TiO_2	0·27	—	—
P_2O_5	0·35	—	—
MnO	—	—	—
CO_2	—	—	—
FeS_2	0·07	—	—
	100·30	100·37	100·00

I: White gabbro, Fell Hill, 1,300 yards south-east of Ardwell (analysed by B. E. Dixon).

II: Albitite, near Pala, San Diego County, California (analysed by W. T. Schaller). Ref. *Washington's Tables*, 1917, 301.

III: Plagiaplite, Koswinsky, Kitlim Dist., Ural Mountains. Ref. *Washington's Tables*, 1917, 303.

Reference may now be made to two interesting exposures of a gabbro-like rock which are found within the serpentine area, close to Colmonell. The first occurs in a shallow quarry at Deafstone and has been described by Teall.[1] The rock is mottled black and white, is distinctly patchy, and has experienced slight crushing. Under the microscope it can be determined as a gabbro carrying abundant colourless pyroxene, intergrown with and passing into brown hornblende, intensely pleochroic red-brown biotite, ilmenite, and apatite. Evidence of stress is afforded by granulation of the felspars and the development of uneven extinctions. The second rock crops out on the ridge at the east end of Clauchanton Hill, not far to the north of Garnaburn and west of the hill road running from that part to Lendalfoot. This is a handsome stone showing large bladed and branching crystals of dark hornblende, and the bronzy lustre of biotite. Microscopically the constituents are disposed in rude schlieren (see Pl. VII, Fig. 3), and the belts include andesine felspar, red-brown biotite, pale green diopside, and brown-green hornblende. The rock carries a good deal of ilmenite, apatite, and sphene. Occasionally it is albitized but this phenomenon is not a striking feature.

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[1] *Sil. Mem.*, 476.

FOLIATED GABBROS AND GRANULITES.

Foliated gabbros may be seen at Fell Hill (south of Byne Hill), at Knockdaw, and on the north face of the Breaker Hill, as well as at various other localities in the Ballantrae region. But, as observed by Drs. Peach and Horne, probably the finest display of these rocks is that laid bare about one-third of a mile east of the farm steading of Millenderdale, where the gabbros form a series of rough knolls or bosses upon the moor. These seem to belong to two great dykes that trend north-east and south-west, the foliation planes dipping generally to the north-west at high angles. Examination here soon discloses many of the more striking features of these flasered rocks. Thus the irregular character of the foliation will be quickly discerned, likewise the fact that though the structure planes strike mainly to the north-east, yet that, sometimes, they change direction and may occasionally be seen oriented nearly east and west. And the variations in texture and mineral composition are likewise splendidly exhibited. The coarse white, or black and white, gabbro is cut by grey, coarse- or fine-grained, granulitic rock, that is not chilled against the environing body. On some of the knolls to the south of the stone fence, running east from Millenderdale farm, the granulite seems to constitute the main mass of the rock, and it might here be thought that the coarse gabbros were intruded into the granulite. But careful examination shows that the granulite often encloses fragments of the coarse rock, and further that the foliation of the latter is distinctly intersected by the doleritic looking material. Some portions of the masses are thoroughly schistose. Others exhibit beautiful augen-structure, large crystals of lustrous brown hornblende forming the eyes. Microscopically some of the Millenderdale gabbros show only large plates of brilliant red-brown hornblende lying in a base of saussurite, that is a mixture of albite, analcite, chlorite, and prehnite. Other examples exhibit nearly colourless pyroxene, edged with brown hornblende, and some contain red-brown biotite. Occasionally narrow zones or belts of somewhat granular fresh andesine or labradorite are found. Among the accessories apatite is often an abundant constituent, titanite is not rare, whilst iron ore, apparently of late separation, affords a striking feature of many sections.

The Millenderdale granulites have been described by Teall.[1] Some of the rocks are highly pyroxenic, some hornblendic, while yet in others the proportions of pyroxene and amphibole are nearly equal. All have their felspathic content in large part replaced by albite, prehnite, pectolite, chlorite, and analcite. Olivine never occurs in these foliated gabbros at Millenderdale, but, on the other hand, some of the granulites carry beautiful enstatite or hypersthene. One of the best localities for collecting hyperstheniferous granulite is that on the west side of the west knoll, north of the stone fence above referred to.

In considering the factors that have been instrumental in producing these flasered and banded gabbros it is quite obvious that some of them are composite or compound intrusions. The fissures or channels they occupy would probably be traversable, or closed, depending on the tangential pressure across the area at the time of their injection. Thus fluctuations in the condition of stress permitted at one time the introduction of fresh magmatic draughts, or brought about the distortion of fractions already emplaced and in process of crystallizing, or already in the solid phase though probably still at a high temperature. The whole matter, it must be conceded, is not one that admits of ready explanation. Sir John Flett's descriptions of the banded gabbros of the Lizard relate to phenomena very closely parallel. Referring to certain gabbro-schist dykes at Spernic Cove, and at Lankidden Cove, on the east side of the Lizard, Sir John Flett writes[2]: "In this case there is no escape from the conclusion that, as the gabbro must have been crystalline before the peculiar augen structure developed, the rock must have passed through a period in which it was solid but extremely plastic. Hence we infer that these dykes were caught by movements of the walls immediately after crystallizing and while they were still very hot." And, further, in concluding his general account of the metamorphism of the Lizard gabbros, "we seem justified in inferring that the consolidation and cooling of the gabbros were attended by stresses and earth-movements to which a large part of the metamorphism is to be ascribed."

Now it is not easy to separate the above injection-foliated masses from other banded and granulitic rocks, that probably owe their character to the operation of dynamothermal processes following closely, although perhaps at a slightly later period, upon intrusive emplacement. Thus in the serpentine area, to the east of the moorland road running between Lendalfoot and Garnaburn, a large number of doleritic-looking masses with Caledonian extension of their outcrops may be seen rising as knolls above the general level. In most cases these rocks are granulites, some being hornblende-felspar-granulites, others hornblende-pyroxene-felspar-granulites, or pyroxene-granulites. One fine rock is a spheniferous hornblende-felspar-granulite, in which the felspar has been replaced in large measure by clear analcite, the whole being traversed by veins of prehnite and analcite. At the east end of a lochan, about one mile north-east from Garnaburn, a curious compact crystalline purplish rock is found, which is a granulite carrying fresh olivine, brown hornblende, colourless pyroxene, and an intermediate soda-lime felspar. The fact of this mass containing olivine indicates perhaps a date for the inception of the metamorphic change. Many specimens of the rock have been sheared, or compressed, so that the olivine now occurs as long bi-tapering crystalline fragments. Some of the granulites are cut by leucocratic veins that may consist of albite, of albite and hornblende, or of albite, hornblende, quartz and biotite. In the field the substance of these is often pure white, resembling a crystalline limestone. Microscopically the masses show distinct evidence of crushing and granulation and as a rule they can be seen to carry an abundant content of sphene. An interesting occurrence, and one convenient of access, is that exposed on the sole of a shallow water channel, upon the east side of the road running from Lendalfoot south-east to Garnaburn, about half a mile north of the latter, and on the 300 feet contour. Here a somewhat granular hornblende-biotite-granite, carrying a notable amount of orthite, intersects and veins a dark hornblende-felspar-granulite, that has been largely albitized. And other similar instances of white veins cutting doleritic granulite are well exposed on the high moor not far to the east of the point noted.

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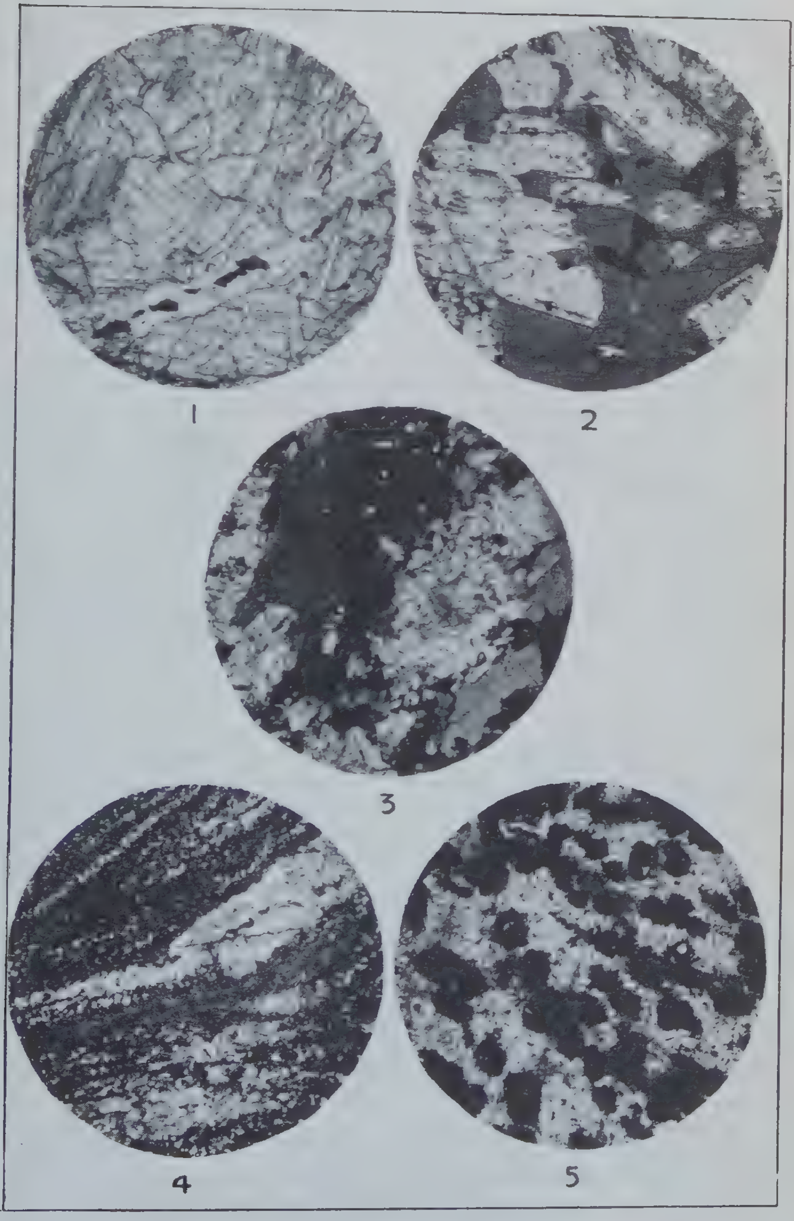
[1] *Sil. Mem.*, 477.

[2] *Lizard Memoir*, 1912, 88 and 89.

All the above rocks have been derived from olivine-bearing and other gabbros and dolerites. One of the most instructive rocks furnishing evidence in support of this opinion is that exposed at the head of Poundland Burn, near the spot where picotite is found in the serpentine. This mass in hand specimen resembles an average saussuritic gabbro, but under the microscope is discovered to be of more than ordinary interest. Originally the rock seems to have been an ophitic olivine-gabbro, but it has experienced severe distortion and the schillered pyroxene, or diallage, and felspar, are in process of granulitization. The former mineral is being converted to granular clear pyroxene and brown hornblende. The original ingredients all exhibit strain phenomena, and the felspars are saussuritized and full of finely divided chlorite, that renders the slides in large part isotropic or, indeed, quite opaque.



IGNEOUS AND METAMORPHIC ROCKS OF THE BALLANTRAE REGION.

[*To face p.* 120.

But it is doubtful if there are in the Ballantrae region any more puzzling or fascinating rocks than those visible upon the slopes of Littleton Hill. The masses here exposed were referred to by Sir Jethro Teall[1] as probably exhibiting a thermally altered phase of the diabase lavas. And they have also formed the subject of papers by Drs. F. Mort[2] and G. W. Tyrrell.[3] The former of these two authors considered them to have been derived from normal ophitic olivine-dolerite by some process of thermal metamorphism. He believed that the granulitic mosaic with a schistose structure might readily be taken as affording evidence of powerful crushing, but he thought in this respect that the appearances were misleading. Dr. Tyrrell's observations differ essentially from those of Dr. Mort in recognising in the rocks distinct evidence of dynamic action (see Pl. VII, Fig. 4). He did not accept Teall's view that the rocks probably represent altered lavas, but rather that their original affinities are with rocks similar to the intrusive gabbros and dolerites so common in the Ballantrae region. Dr. Tyrrell concluded that the rocks should probably be regarded as relics of an older mass of gabbro or dolerite enveloped by the later serpentine.

My own investigation of the above rocks points to conclusions slightly different from those arrived at by previous workers. The rocks seem to be sheared and granulitized originally banded dioritic gabbros or dolerites, for the remains of gabbroic or doleritic texture can frequently be seen, a fact formerly noted by Dr. Tyrrell. Mineralogically the masses consist of granular brown or red-brown hornblende, orange-red biotite of an intense pleochrism, and a mid- or distinctly sodic felspar. Apatite is abundant in some of the rocks, likewise iron ores and titanite. A feature somewhat difficult to understand is the manner in which the latter have become in part moulded upon the other constituents. In one section a thin string of titanite of late crystallization could be seen cutting indifferently across the fabric of the rock. Some of the rocks are pseudo-porphyritic and at least in one excellent exposure fine granulitic bands alternate with what originally was probably a coarsely gabbroic material but which is now reduced to "porphyrite" with distorted "phenocrysts" of felspar. It may be added that olivine, although not a common ingredient of these granulites, occurs sparingly in some of them. All the masses are distinctly environed by serpentine but no good contacts have been found. An analysis of one of the "porphyrites" collected north of Bougang yielded the results printed below. The figures indicate that we have here a persodic type comparable with, amongst others in a relatively small group, the bekinkinite of Rosenbusch.

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[1] *Sil. Mem.*, 480.

[2] "The Passage of a Dolerite into a Hornblende Schist," *Trans. Geol. Soc. Glas.*, xiii, 187.

[3] "A New Occurrence of Picrite in the Ballantrae District and its Associated Rocks," *Trans. Geol. Soc. Glas.*, xiii, 283.

	I.	II.	III.
SiO_2	45·70	45·99	43·60
Al_2O_3	13·60	13·42	13·60
Fe_2O_3	2·32	4·63	3·95
FeO	9·47	6·48	6·95
MgO	10·53	12·29	10·20
CaO	10·08	9·01	12·10
Na_2O	3·74	4·32	3·74
K_2O	0·56	0·61	0·69
$H_2O > 105°$	1·19	1·05	2·75
$H_2O < 105°$	0·01	—	—
TiO_2	2·60	1·71	2·44
P_2O_5	0·26	0·40	0·43
MnO	—	·55	—
CO_2	—	—	—
FeS_3	0·08	—	—
Cr_2O_3	0·14	—	—
	100·28	100·46	100·45

I: Hornblende-granulite, 800 yards north of Bougang, 2 miles west of Colmonell (analysed by B. E. Dixon).

II: Olivine-diabase Nieder Putskau Lausitz (analysed by M. Voigt). Ref. *Washington's Tables*, 1917, 687.

III: Bekinkinite (Rosenbusch) Bekinkina, Ambavatovy, Madagascar (analysed by Pisani). Ref. *Washington's Tables*, 1917, 687.

Dr. Mort averred that unmodified ophitic dolerite might be collected in this area at the summit of Littleton Hill, but that as we passed southwards other types were encountered exhibiting an increased metamorphic effect. Such a conception I regard as probably erroneous, for not far to the east of Littleton Hill lies Balhamie Hill upon the ridge of which some of the finest dioritic schists and granulites occur, in close proximity to dolerites that are almost unchanged. And on the south slope of Balhamie Hill, cutting the serpentine, there is one narrow vein of cognate olivine-dolerite, carrying fresh pale brown pyroxene, that shows almost a normal igneous structure. It is not possible to trace lithologic transitions here over any great lateral extent, for the country rock is clearly serpentine and the volume of the dolerites and granulites relatively very small.

The date and details of the metamorphism of the above rocks afford difficulty, however. If attributable to any widespread dynamic processes one might expect to find a parallelism over the area of the effects produced, but there is no constancy in the strike of the structure planes that have been developed. In the granulites on the north face of Littleton Hill, sometimes these lie north-east and south-west, whereas on the south slope they trend nearly north and south. Further the serpentine that environs the masses has not been tremolitized or altered in any way, but is normal bastite-serpentine. The rocks appear to have been reconstituted by powerful stresses immediately after having assumed the solid phase. The masses may have been originally introduced into variously, although consistently, oriented rifts in the peridotite, which tending to close up on the still hot rock bodies resulted in their reconstruction. The only likely alternative to this interpretation is the xenolithic hypothesis of Dr. Tyrrell, which it must be conceded has the merit of throwing light upon a puzzling feature, namely, that some of the rocks present in the field a slightly hornfelsed appearance.[1]

SCAPOLITE-AMPHIBOLITES.

Upon the north face of Littleton Hill several types of melanocratic granulite are exposed, in a series of small knobs rising out of the sheep-pasture. Some of the masses are schistose hornblende-granulites, whilst others are granulitic gabbro-diorites or hornblende-dolerites. One of the rocks there visible was described by Dr. Tyrrell as hornblende-picrite. Nearly all are of doleritic texture. In thin section some of the slices show the felspars to have been replaced by turbid albite and analcite, and occasionally the rocks are veined by these substances. An interesting example is that outcropping upon the acclivity of the hill, in line with the ruined stone fence extending due south from South Ballaird farm. This consists essentially of long prisms of deeply coloured brown, or green-brown, hornblende, having a tendency to idiomorphic development. The ferromagnesian seems formerly to have been enclosed in large plates of soda-lime felspar, but that constituent is now found mainly in the granulitic condition. Apatite and iron ores are abundant accessories; the former in large needles, and the latter as grids in the early separated amphibole. The usual orange-red biotite, probably of secondary genesis, is a striking ingredient of variable amount. But the feature of special note in the rock is the appearance of granular or platy scapolite, replacing the felspar. The mineral is quite clear and colourless, exhibits good rectangular cleavages, and yields in convergent light a uniaxial figure of negative sign. In very thin slices the birefringence sinks to about the level corresponding to quartz. The rock is thus identified as scapolite amphibolite (see Pl. VII, Fig. 5). Such a petrographic type must certainly be rare in the Ballantrae region although it is proper to state that it may yet be recognized among the mineralogically similar gabbro-diorites and granulites at the east end of Clauchanton Hill.

ALBITE-DIABASES.

Reference to the current edition of the published 1-inch map of the Geological Survey of Scotland, sheet 7, will show that a large number of intrusive rocks of the area are indicated by a bright green colour. Some of these masses are coarsely crystalline gabbros that may be flasered or foliated, others are granulites, whilst a considerable number consist of rocks exhibiting the normal of dolerites. Especially to advantage can the last noted be observed on the shore just north of Lendalfoot, or on the high serpentine moors that sweep inland from the sea. On the moorland they show as bare knolls, and very often the nature of the exposure indicates a north-east–south-west extension of the rock bodies. At Lendalfoot the intrusives stand up wall-like and clear-junctioned against the serpentine. In thickness they range up to about 30 feet in cross measurement, but they are conspicuously capricious in their mode of occurrence, being twisted and ending off, or thinning very quickly, in their short course across the strand. That this is an original feature and not due to faulting, or pinching-out, may be inferred from the chilled margins, which are excellently shown. Where the whinstone abuts against serpentine the texture becomes porcellanous and the colour very pale, or indeed nearly white. It is a point worth noting that many of the masses are chilled right over their actual summits thus exhibiting at the present day their original upward terminations.

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[1] And it is right to add that many of the relict felspar crystals of the above granulites exhibit the curious type of clouding, or schillerization, which Mr. A. G. MacGregor has recently recognized as a characteristic effect of thermal metamorphism. Ref. *Min. Mag.*, xxii, 524. D. B.

South of Bonney's Dyke there is a sandy stretch of beach, or little bay, on the south side of which a rugged group of intrusive masses occurs prominently on the foreshore. This is an especially instructive part of the coast. Here thin veins of dolerite may be seen to intersect the serpentine, and thereby to indicate their later intrusive date. And the countless strings and veins of white pectolite, that must have been introduced into fissures in the cooling and contracting diabases, likewise arrest attention. These veins may sometimes be seen coming down against the serpentine junctions, but the latter rock they never cut. Such an observation might easily lead one to infer some sort of xenolithic relation for the diabase masses: the evidence, however, favouring their interpretation as normal intrusive rocks is overwhelming.

Perhaps a more interesting matter is to convince oneself of the dyke form of these intrusions. Current opinion, it must be remembered, believes that the whole of the Ballantrae igneous province was severely compressed, and its rocks folded and subjected to denudation, in immediately post-Arenig time. And, further, that the same rocks again experienced intense directed pressure at the time of the main Caledonian folding. Yet the dykes emerge just as if they had been emplaced subsequent to all these geological vicissitudes. Consideration of the probable sequence of events in the Ballantrae region early led me to the belief that the masses might really be folded sills, and though conclusive evidence bearing upon this matter has not been obtained, nevertheless there is one fairly good instance, north of Lendalfoot, of a dolerite "dyke" in the serpentine which is folded into a synclinal trough. Some of the masses are strikingly porphyritic, others non-porphyritic, and the two varieties pass into one another, or occur as composite intrusions, the mass just referred to, as outcropping in synclinal form, having a porphyritic centre, but quite non-porphyritic upper and lower portions.

Passing on to an examination of the microscopic structure of the rocks it may be said that they consist of plagioclase felspar and monoclinic pyroxene, along with the accessories ilmenite, hornblende, biotite, and apatite. The pyroxene, in many cases quite unaltered, may be nearly colourless or of a purplish titanium-bearing variety, when it possesses a distinct dispersion of both axes and bisectrices. Common modes of occurrence are as needles elongated parallel to the third crystal axis, and as sub-ophitic plates, often with an edging of green or brown hornblende. 2V of the pyroxene, as determined on the Fedorow stage, yielded values of 52°–54°. Ilmenite occurs in long shreds and skeletal crystals, usually associated with red biotite. The felspar of these rocks is albite, generally turbid and full of inclusions. As the result of long and careful examination the conclusion has been reached that this mineral is invariably of secondary origin, and replacing a soda-lime felspar that has disappeared. Some of the porphyritic dolerites especially show the process of replacement in clear manner. One part of a mass may be albite-bearing dolerite, another part of the same mass normal dolerite, with fairly basic felspar. In the rocks that are partly albitized it is interesting to see the contact between the two minerals, the original soda-lime felspar quite clear and of a cold white colour, the albite of a warmer tint and full of secondary products such as chlorite and prehnite. The latter mineral is one of the first substances to replace albite, and this substitution effects the process known as saussuritization. Examples of saussurite consisting merely of turbid or cloudy albite can be seen in some of the rocks. But in others the prehnite has replaced or impregnated the albite, giving a much more highly refringent and hard opaque substance. It is this mixture of prehnite and albite that often forms such a puzzling microscopical feature of these altered dolerites and gabbros of the Ballantrae region. The results of chemical analyses of two typical examples of the Lendalfoot albite-diabases are given on p. 126.

The problem of the origin of the spilites and spilitic diabases has in recent years been discussed by various investigators. Eskola[1] ascribes the widely observed albitization to a stability transition with falling temperature, the phase complex virtually passing into a new thermal domain and thus requiring reconstruction. In this connection he derives evidence from Morey and Bowen's work on the Na_2SiO_3–SiO_2 system[2] and expresses himself in these terms: "Alkali silicates are thus, besides water, these substances that remain last fluid in crystallizing magmas and, as a rule, are squeezed away before complete consolidation. But in case they are trapped in the mesh of crystals—they will cause a rearrangement of the equilibria of the higher temperatures and change the calcic plagioclases into albite." The reaction involved might accord with the equation :—

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[1] "On the Petrology of Eastern Fennoskandia. I: The Mineral Development of Basic Rocks in the Karelian Formations," *Fennia* 45, No. 19, 90 (Helsingfors, 1925).

[2] *Jour. Phys. Chem.*, 28, 1924, 1167.

$$CaAl_2Si_2O_8 + Na_2SiO_3 + 3SiO_2 \rightarrow 2NaAlSi_3O_8 + CaO.$$

Eskola thinks that a large part of the lime thus set free might perhaps be carried away in solution.

	I.	II.
SiO_2 . . .	46·47	47·50
Al_2O_3 . . .	12·87	12·39
Fe_2O_3 . . .	2·40	4·17
FeO . . .	11·68	10·60
MgO . . .	5·48	4·27
CaO . . .	9·97	7·37
Na_2O . . .	4·00	4·88
K_2O . . .	0·68	0·89
$H_2O > 105°$ . .	2·56	2·62
$H_2O < 105°$ . .	0·06	0·20
TiO_2 . . .	3·69	4·49
P_2O_5 . . .	0·50	0·78
MnO . . .	—	—
CO_2 . . .	—	—
FeS_2 . . .	0·09	0·02
Cr_2O_3 . . .	0·02	—
	100·47	100·18

I : Albite-diabase, half a mile north of Lendalfoot outcrop in field east of Girvan-Ballantrae road (analysed by B. E. Dixon).

II : Albite-diabase outcrop on west side of Girvan-Ballantrae road, 200 yards north of Chapman's Craig, S. of Lendalfoot (analysed by B. E. Dixon).

Sundius[1] in an interesting paper recently published seeks to resolve the difficulty of the ophitic structure of many of the spilitic greenstones by conjecturing, in respect of their generally high iron content an expansion of the crystallization range of albite. But, as a further elucidation, he states that, after the crystallization proper, a secondary alteration has occurred in most of the described rocks of the spilitic group and the felspar is hereby changed into a nearly pure albite.

Yet other researchers, Beskow[2] and Backlund[3], have devoted careful study to the matter. The former reaches the conclusion that the albitization of the spilites " ist unter dem Einfluss der Meereswassers vor sich gegangen ". Backlund, however, inclines to the initial explanation of Dewey and Flett. Thus he writes :

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[1] " On the Spilitic Rocks," GEOL. MAG., LXVII, 1930, 1.

[2] " Södra Storfjället im südlichen Lappland," *Sveriges Geol. Unders,* Årsbok 21, 1927, No. 5, 1929.

[3] " Die Magmagesteine der Geosynklinale von Nowaja Semlja," *Report of the Scientific Results of the Norwegian Expedition to Nowaja Zemlya,* 1921, No. 45, 1930.

"Die Spilite sind chemisch selbstständig; der von Diabasen abweichende Mineralbestand (Albitisierung) wird durch Akkumulation von Restlösungen, also durch Autometamorphose bewirkt; wirksam sind hierbei angehäufte (wässerige ?) Lösungen von Na_2CO_3 und CO_2, die zur Erniedrigung der Temperaturen der Letztkristallisationen beigetragen haben (u.a. engl. Autoren: Dewy und Flett). Die Karbonatlösungen mögen auch SiO_2 geführt haben, und es mag sich um die Temperaturverschiebungen des Gleichgewichts

$$Na_2CO_3 + SiO_2 \rightleftarrows Na_2SiO_3 + CO_2 [+ nH_2O]$$

im grossen Ganzen gehandelt haben."

Without further discussion it may be recalled that Dewey and Flett's view published twenty years ago pictured the spilitic magma and the rocks derived from it as initially rich in soda. The chemical analyses submitted in this paper confirm that opinion. Ultimately, as will be seen, the magma of the Ballantrae province differentiated to a thoroughly sodic pole, resulting in the production of soda-granites and trondhjemites. Notwithstanding what has been said, it is necessary to repeat that the "porphyritic tachylyte" of Stockenray appears rather to indicate that the albitized lavas have originated as the result of subsequent hydrothermal sodification.

The Lendalfoot diabases are veined by pectolite and some of this mineral occurs in thin strings, when it is liable to be confounded with prehnite, which similarly is found in the rocks. Both substances are optically positive, pectolite has two cleavages prehnite only one, but in the latter sometimes a parting at right angles to this renders it difficult to say which is the correct determination. Immersion in oils helps little, the refringences being of nearly equal value. Probably the best way to discriminate between pectolite and prehnite is to examine the behaviour of small fragments in the Bunsen flame. If the substance is prehnite it will be seen to intumesce markedly before fusion. In contrast to this pectolite fuses quite without intumescence. The hardness critically tested affords too a helpful guide in deciding. As stated, both types of veinlet occur in the albite-diabases; fine pearly strings of pectolite, lustreless ones of prehnite, and there are probably cases where the two minerals are mixed. Yet in other rocks of the same group the veins are filled with translucent analcite, which sometimes under the microscope can be seen to have replaced the secondary albite felspar.

It must not be thought, although admirably displayed there, that the albite-diabases are confined to the Lendalfoot shore. Beautiful instances occur at various places inland, some of the finest examples being exposed within the serpentine area, on the moor about one mile directly east from Pinbain. The albite-diabases always show normal igneous structures and are markedly chilled along their contacts. They seem to be of distinctly younger date than the flaser gabbros and granulites, which usually exhibit a different type of junction with the serpentine.

GRANITES.

The two well-known granites of the Girvan-Ballantrae district occur at Byne Hill and Grey Hill, which eminences form the culminations of the high ridge that sweeps parallel to the coast, between Woodland Bay and Pinbain. On the north-west side of this elevated tract the Benan Conglomerate, and overlying Balcletchie Beds, dip uniformly at a high angle to the sea. If one imagines horizontality restored to the bedded rocks, but a little of extra thickness would carry them uninterruptedly across the igneous core of the range. Nowhere in this country is one fortunate enough to find the basement members of the Barr Series lapping unconformably against an old bank of the Ballantrae rocks. That indeed would be a gratifying discovery, for it would convey much needed confirmation of existing physical interpretations.

In reflecting upon the source of the materials that make up the Girvan conglomerates, it is helpful to keep in mind the character of the detritus lying at the present day upon the Girvan-Ballantrae foreshore, where a large exposure of the Arenig igneous province abuts against the western sea. Ought not the shingle and waste meantime reposing there to correspond with what we now find sealed up in the conglomerates? Yet such characteristic rocks as the bastite-serpentine and flaser-gabbros, lying abundantly upon the shore to-day, are inconspicuous in the conglomerates, supposedly resulting from the degradation of the identical igneous terrane. Certain reasons founded upon inference afford ground for believing that current opinion, as stated in the Upland Memoir, is not essentially in error, yet it is certainly desirable that further evidence should be adduced in favour of the view there set forth.

The central granite of the Byne Hill was described by Sir Jethro Teall as a biotite-granite with oligoclase, orthoclase, quartz and biotite. It is not easy to collect fresh material either from this mass or that of the Grey Hill. The best specimens obtained show a rock carrying quartz and albite, along with red-brown biotite and green hornblende. Orthoclase felspar and oligoclase could not be determined in any of the sections. The rocks are soda-granites, or trondhjemites, and the analytical details given on p. 129 afford satisfactory proof of the correctness of that identification.

Two curious rocks, that may be referred to here, occur respectively upon the north-west slope of Knockdolian, and on the north face of Knockormal Hill, south of Lendalfoot. The former is a fine white syenite that has been fragmented in proximity to the south boundary of the serpentine, which must at this point be near at hand. It is made up of albite, along with subordinate orthoclase and analcite, discoloured biotite, and green hornblende. A fair quantity of sphene is present in some portions of this mass, which, it may be observed, is of a type unique in the district. The Knockormal rock builds some prominent crags on the north slopes of the hill west of Knockormal farm, is of a dark green colour in the field, and has a strangely mottled appearance. Microscopically it consists of albite, green hornblende, brown biotite, and quartz. The last noted constituent appears extensively to have corroded and replaced the felspar and now occurs in symplectic association with that mineral. The rock shows abundant evidence of cataclasis, of a date later than the quartzification.

	I.	II.	III.
SiO_2	70·18	69·30	70·30
Al_2O_3	14·24	16·81	15·36
Fe_2O_3	0·16	0·28	0·56
FeO	4·64	1·26	2·37
MgO	0·71	1·08	1·03
CaO	1·44	3·34	3·52
Na_2O	6·09	6·00	4·30
K_2O	0·73	1·39	1·45
$H_2O > 105^\circ$	0·88	0·50	0·79
$H_2O < 105^\circ$	0·34	—	0·05
TiO_2	0·46	0·23	0·35
P_2O_5	0·23	0·03	0·12
MnO	—	—	0·04
CO_2	—	0·15	0·13
FeS_2	0·19	—	0·03 (sulphur)
	100·29	100·37	100·40

I : Soda-granite or Trondhjemite, summit of Byne Hill, Girvan (analysed by B. E. Dixon).

II : Trondhjemite, Dragaasen bei Reitstoen, Guldalen (analysed by O. Roer). Ref. V. M. Goldschmidt, *Vid.-Selsk. Skrifter I, M.-N. Kl.*, 1916, No. 2, 79.

III : Trondhjemite, Mastravarde, Mosterö, Stavanger-Gebiet (analysed by O. Roer). Ref. V. M. Goldschmidt, ibid., 85.

DYKE ROCKS.

The dyke rocks of the region fall readily into three groups, viz. :—

(*a*) Dykes of Arenig age (other than doleritic granulites and albite-diabases).

(*b*) Dykes of Devonian age.

(*c*) Dykes of Tertiary age.

(*a*) The rocks here briefly noted are probably of commoner occurrence over the Ballantrae district than formerly suspected. It seems likely that they have not been recognized for the reason that no good field criteria are available to discriminate them. An excellent example of the group has been laid bare by the sea at the north end of Stockenray Bay, where it can be seen to intersect the diabase-porphyrite lava. Specimens cut from this mass show it to be an albitized andesite, carrying large phenocrysts of idiomorphic albite and less abundant fresh augite. The ground shows a fluxional arrangement of little albite laths, and a good deal of magnetite is present. Blocks of a similar petrographic character, it may be observed, are found in the ash exposed on the roadside, at the south end of the bay (near the spot where certain fossiliferous black shales described in the Upland Memoir, 444, are visible). Some other rocks from the coastal and inland areas seem also to belong to this group.

(*b*) These are pink, felspathic, usually altered rocks, consisting of plates of albitized plagioclase along with abundant apatite, magnetite, chlorite, and calcite, and carrying numerous elongated prisms of pale brown hornblende, and interstitial quartz. The amphibole shows generally in cross section the primary prisms and the secondary pinacoïds. The determination of the rocks is often difficult on account of their altered state, but there can be little doubt that they belong to the Devonian hornblende-porphyrite—spessartite group of dykes, long known to have a considerable development in certain parts of the Uplands.

(*c*) The Tertiary igneous dykes intersecting the strata of the Whitehouse Group, exposed on the shore between Woodlands Bay and Ardwell farm, and cutting the older volcanic series south of Kennedy's Pass, consist of basalts and dolerites. For the purpose of comparing them petrographically with occurrences not too remote, and about whose geological age one might feel reasonable certainty, I paid, in company with Mr. R. J. A. Eckford, a visit to Ailsa Craig, where we collected a number of the dykes that there intersect the riebeckite micro-granite. Upon examination, these rocks were ascertained to include olivine-basalts of Tertiary plateau facies and crinanitic olivine-dolerites. Several members of the suite, however, could not be so precisely determined. Rather did they seem, from carrying a small amount of residue or glass, to afford evidence of a relationship with the tholeiites and quartz-dolerites. On the mainland, south of Girvan, the dyke rocks are of compact texture. The majority are plateau-basalts or dolerites, some being markedly porphyritic in respect of olivine. But, as on Ailsa Craig, there occur here, too, a few somewhat decomposed and altered dykes that probably belong to the saturated and over-saturated group.

CONCLUSION.

The widespread manifestation of the processes of albitization, and the thoroughly sodic character of the pole to which the magma of the Ballantrae province differentiated, are the outstanding petrographic facts brought forward in this paper. I regret inability yet to present any new synthesis of the natural history of the area. The succession of events was not the simple one—volcanic phase, plutonic phase, and phase of minor intrusions. Lately discovered blocks of albitized gabbro in certain bedded ashes at Pinbain, and near South Ballaird, as well as various other considerations, indicate the need for further work in the field. When this has been carefully carried out it may be possible to contribute a new and fuller chapter to the igneous geology of the district.

In conclusion I should like to express sincere thanks to Sir John Flett, who first counselled me to take up work in the Ballantrae country. Repeatedly has he cautioned me as to the necessity for exercising care whilst dealing with rocks that have been extensively albitized, and it is primarily to him that I am indebted for the excellent series of chemical analyses. Also must I acknowledge with gratitude the services of Messrs. Andrew White, Girvan, and R. J. A. Eckford, H.M. Geological Survey, who upon many traverses rendered valuable assistance in the matter of collecting material for petrographic examination.

EXPLANATION OF PLATES V–VII.

Plate V.

Fig.
1.—The Girvan-Ballantrae Hills. View looking south from Girvan Harbour.
2.—Intrusions of albite-diabase cutting serpentine, shore north of Lendalfoot.

Plate VI.

1.—Non-porphyritic spilite, summit of Carleton Hill, Lendalfoot. 20 diameters.
2.—Non-porphyritic spilite, near Port Vad, north of Bennane Head, showing "froth invaded vescicles". Ref. *Tert. Mull Mem.*, 1924, 151. 20 diameters.
3.—Non-porphyritic spilite, above Downan Point, south of Ballantrae. 20 diameters.
4.—"Porphyritic tachylyte." Stockenray Bay. 20 diameters.
5.—Porphyritic pyroxenite, hill-slope, north-west of Laigh Knocklauch, 3 miles north-east of Lendalfoot. 15 diameters.

Plate VII.

1.—Bronzitite, 600 yards west of Laigh Knocklauch. 15 diameters.
2.—Ophitic hornblende-gabbro, north end of Fell Hill, ½ mile east of Ardmillan House. 15 diameters.
3.—Gabbro-diorite, east end of Clauchanton Hill, showing bands of green-brown hornblende, felspar, chrome-diopside, and orange-red biotite. 15 diameters.
4.—Schistose hornblende-granulite, 800 yards north of Bougang, 2 miles west of Colmonell. This rock affords clear evidence of dynamic action. 15 diameters.
5.—Scapolite-amphibolite, north slope of Littleton Hill. Dark prisms of green-brown hornblende, granular felspar, and scapolite. 15 diameters.

The Hunstanton Red Rock.

By R. H. Rastall.

In the January number of this Magazine there appeared a rejoinder by Messrs. Kitchin and Pringle to observations published by myself on their reading of the stratigraphical position of the Hunstanton Red Rock and its relation to the beds above and below. Since the following is intended as an answer to this, it is almost inevitable that it should be written in the first person. For this unavoidable egotism apologies are offered to readers.

In the first place I would remark that the paper of Messrs. Kitchin and Pringle is devoted almost entirely to a detailed criticism of myself for not having done just exactly that which I expressly intended not to do; that is, to discuss the stratigraphical age of the strata in question. In an earlier paper in this Magazine they arrived at conclusions, based on palaeontological data, which were in flagrant contradiction of my own reading of the field relations, as set forth in *Geology in the Field* in 1910. Many years before the appearance of their conclusions I had carried out some rather casual (and unpublished) work on the petrography of the Red Rock, which aroused my interest in its unusual nature, and I therefore determined to examine the sections afresh, to collect material, and to carry out as complete a petrographical examination as possible, in order to see whether such work would throw any light on the apparent discrepancy.

When I looked up the literature I found that Prof. Judd and Prof. Wiltshire had published readings of the Hunstanton cliff section agreeing exactly with my original interpretation; namely, that the Carstone passes up continuously without any visible break into the Red Rock, and that the Red Rock is separated from the Chalk by a conspicuous discontinuity, marked by a seam of red argillaceous material. The examination of the material collected at Hunstanton cliff and at Snettisham occupied all my available time for a whole year, owing to the tediousness of the methods rendered necessary by the peculiar lithological character of the rocks. The results attained are set forth in minute detail in my paper of 1930. From the petrographical point of view they entirely confirmed my reading of the field evidence and that of Judd and Wiltshire. In my paper detailing these results nothing was said as to the stratigraphical age of the various subdivisions there recognized. The treatment was entirely physical and petrographical.

Nevertheless, Messrs. Kitchin and Pringle criticize me for not having said, in effect, " my results are so-and-so, but of course they must be wrong, because they do not agree with orthodox palaeontological dogma." And they ask me to find some far-fetched explanation which will fit their conclusions. I must here repeat that I was not trying to prove anything: I was endeavouring to test theory by unbiased observation.

A point of minor importance in the discussion is the famous quotation by Barrois of a sentence, detached from its context, from Judd's summary of the Lincolnshire succession under the name of the " Hunstanton Limestone ". It is unnecessary perhaps to discuss the state of Professor Barrois' opinions when he wrote this paragraph, but the fact remains that it has caused much trouble to Norfolk geologists, in view of the categorical statement to exactly the opposite effect regarding the succession at Hunstanton earlier in the paper by Judd from which it is quoted.

As regards the succession in Norfolk, which was the sole subject of my paper, the question resolves itself into two distinct problems: (*a*) the relations of the Carstone and the Red Rock, and (*b*) the relations of the Red Rock and the Chalk. These must obviously be treated separately, since the first involves the statement by Messrs. Kitchin and Pringle that what appears to be a continuous succession really represents two distinct formations separated by a long gap in time; while the second implies that two rock beds separated by an obvious discontinuity really indicate a nearly complete succession, with a trifling hiatus between them, due to a slight variation of local conditions.

(*a*) THE CARSTONE-RED ROCK SEQUENCE.

The Carstone of Norfolk forms the upper part of the supposed Aptian series, with the Snettisham Clays and the Sandringham Sands below. The total thickness of the Carstone appears to be about 40 feet, and it is only quite near its base that any fossils have been found. It is admitted that for about 35 feet below the base of the Red Rock there are no fossils at all, and therefore no palaeontological evidence of the age of this mass of sand. Further, it is admitted that some at any rate of these basal fossils are derived from older formations, including apparently all the ammonites, which are the recognized zone-fossils of this age. I submit therefore that there is no palaeontological evidence for the age of by far the greater part, about seven-eighths, of this mass of sand.

Now I am well aware that the facts stated in the following sentences are not of much value as evidence, but they seem worthy of some consideration. In the large quarry at Snettisham where the Red Rock is exposed there is a considerable difference of lithological character between the upper and lower parts of the Carstone. The lower part is a hard, well-cemented, and well-jointed ferruginous sandstone, excellently suited for building, while the upper part, estimated at about 6 feet, is a soft and almost incoherent sand, which passes up without any visible break, except a change of colour, into the Red Rock. If there is anywhere a stratigraphical discontinuity within the Carstone, I am inclined to suggest that it may occur here, and not at the top of the Carstone as usually defined. The section at Snettisham is not large enough to show whether this change of character in the Carstone is general or only purely local. Messrs. Kitchin and Pringle seem to assume that a sandy ferruginous deposit cannot be Albian, but long ago the late Sir A. Strahan stated his opinion that the "Carstone" of the Isle of Wight is more closely related to the Gault than to the Greensand.

There is another possibility which I suggest with some diffidence, namely; that *all* the "zone-fossils" of the Norfolk Carstone are derived, and that the hiatus, if any exist, is really below its base, where alone fossils are recorded. It should be remembered that the Carstone is not quite similar lithologically to the "Lower Greensand" of Cambridgeshire and Bedfordshire, and its heavy minerals are different, as I myself showed thirteen years ago. This statement as to heavy minerals applies also to the Sandringham Sands.

At this point I can only repeat my former statement, that a detailed petrographical examination of material from both Hunstanton and Snettisham affords no evidence of a physical break between a horizon well down in the Carstone and the top of the Red Rock. The same peculiar type of sand-sedimentation continues throughout, while the calcareous and argillaceous material of the Red Rock facies merely indicates an addition to the supply of material, and not a revolution in its general character.

(*b*) THE RED ROCK—CHALK SEQUENCE.

In this part of the problem one simple fact is undisputed, namely: that the top of the Red Rock is separated from the base of the so-called Sponge Bed by a seam of dark red material of variable thickness, usually about 2 inches. Furthermore, both the top of the Red Rock and the base of the Sponge Bed are somewhat irregular. Messrs. Kitchin and Pringle maintain that the uppermost part of the Red Rock, about one foot thick, is palaeontologically part of the Cenomanian and that the red seam represents a merely negligible interruption of the processes of deposition.

I am quite prepared to believe on sufficient palaeontological evidence that the fauna of the top block of the Red Rock is Cenomanian, as indeed was stated indirectly in my paper, but I do venture to offer a protest against the following sentence, quoted from Vol. LIX of the GEOLOGICAL MAGAZINE, 1922, p. 195. "We have been able to detect no sign of a break between the base of the Red Rock at Hunstanton and the overlying unstained Chalk." This of course necessarily implies that there is no break between the *top* of the Red Rock and the Chalk. In my paper of 1930, I gave a detailed description of the results of my petrographical examination of the red seam that separates these two formations. It will be well to consider somewhat fully what is implied in the statement of those results, as I think Messrs Kitchin and Pringle have somewhat under-estimated the magnitude of the physical changes involved.

(*a*) Chemical analyses show that the material of the red seam is essentially similar to the red colouring matter of the Red Rock in a concentrated form. The red seam is, therefore, in all probability, a solution-residue of a considerable thickness of Red Rock. On any other theory it is difficult to see where it could have come from.

(*b*) The red seam contains heavy mineral grains exactly similar to those of the Carstone and of the Red Rock, which are peculiar and characteristic.

(c) In addition to the heavy minerals above mentioned, there is a flood of an entirely different assemblage of heavy minerals, of unknown origin, which must have been brought in from some hitherto untapped source by a change in physical conditions.

(d) The lowest part of the Sponge Bed (Chalk) shows no trace of any red colouration and contains no heavy minerals of any kind, thus implying a cessation of former sources of supply and the initiation of another complete change of physiographic environment.

If this complicated sequence of events is to be accepted as "complete conformability" or some equivalent expression, I can only repeat my former remark that certain fundamental definitions of geology are in need of restatement.

From the arguments set forth here, I find myself compelled to maintain that in spite of the palaeontological arguments of Messrs. Kitchin and Pringle, and in spite of the quotation by Prof. Barrois of one of two exactly contradictory statements by Prof. Judd, the Carstone at Hunstanton passes up without any break into the Red Rock, and the Red Rock is separated from the Sponge Bed, the base of the Chalk, by a notable discontinuity.

It is obvious that this discussion might continue indefinitely, which is not desirable. If Messrs. Kitchin and Pringle care to reply to this, their contribution will of course be published in the GEOLOGICAL MAGAZINE: thereafter, so far as I am concerned, the subject may well be allowed to drop. I am, at any rate, grateful to them for their kindly appreciation of my well-meant efforts towards a petrographical elucidation of this thorny problem, which only seem to have made the matter more mysterious.

A Composite Lava from Kintyre.

By W. J. McCallien, D.Sc., F.R.S.E., Glasgow University.

(PLATE VIII.)

W. Q. KENNEDY has directed attention[1] to the existence of composite lava flows and has described in detail composite flows from Inverkip on the Firth of Clyde. In a preliminary work[2] on the igneous rocks of Kintyre the writer has described lavas of the same age (Calciferous Sandstone) as the Renfrewshire flows, but separated from them by the Firth of Clyde and the Kilbrannan Sound. The Kintyre Carboniferous lavas were, of course, once part of the Clyde Plateau to which the Renfrewshire lavas also belong. It is hoped to make a further study of the Kintyre lavas in the field, and a careful look out will be kept for phenomena of the type described by Kennedy. However, on looking over the existing slices of Kintyre Carboniferous lavas in the collection of the Geology Department of the University of Glasgow, a slide was found which is of sufficient interest to merit separate description. The rock from which the slide was cut was collected as a lava specimen only, and nothing noteworthy was noticed at the time. In the light of Kennedy's discoveries and conclusions, however, it takes on a special interest.

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[1] GEOL. MAG., LXVIII, 1931, 166–81.

[2] *Trans. Geol. Soc. Glasgow*, xviii, 1, 1928, 40.

Kennedy attaches four conditions to the definition of a composite lava. These are :—

(1) The flow consists of two easily recognizable rock types.

(2) The arrangement of the two rock types is asymmetric.

(3) The two rock members do not chill against one another, nor is there any intervening slag. The mutual contact is indicative of simultaneous liquidity.

(4) The flow is bounded above by a slaggy, vesicular top and below by a slaggy, brecciated base which leaves no doubt as to the effusive nature.

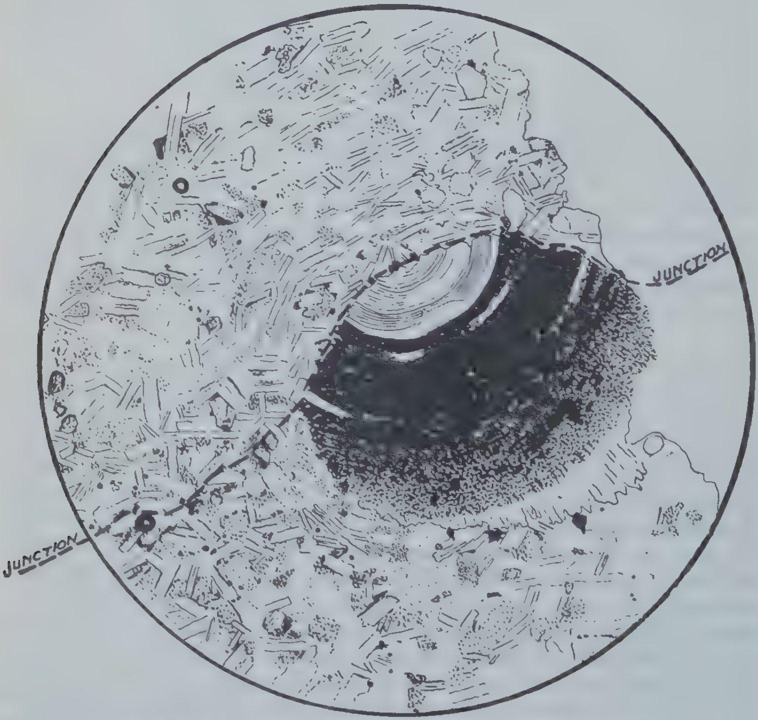

Fig. 1.—Microdrawing of eroded vesicle in composite lava showing approximate boundary between the two lavas. The upper, with flow structure, is considered to be the younger.

In the occurrences discovered by Kennedy no chilled contact or intermediate layer of slag separates the lower non-porphyritic mugearitic variety from the upper porphyritic type. The groundmass of the former is in perfect continuity with the groundmass

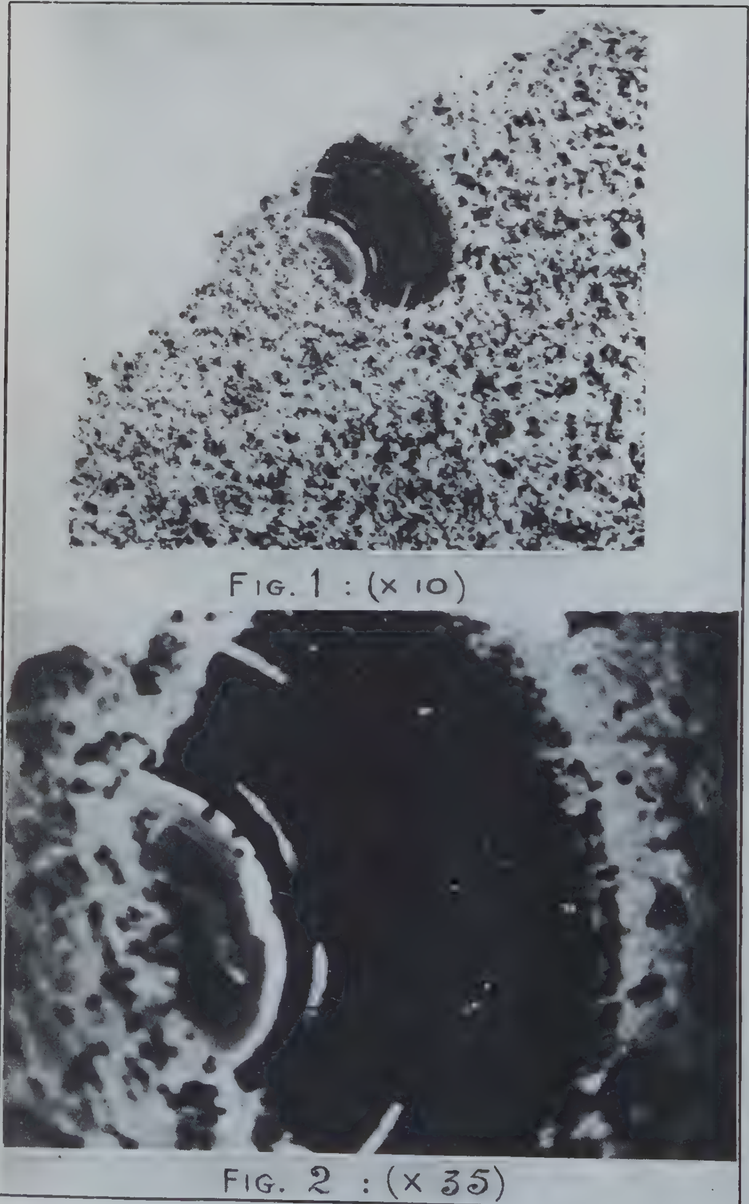

FIG. 1 : (× 10)

FIG. 2 : (× 35)

PHOTOMICROGRAPHS OF ERODED VESICLE IN COMPOSITE LAVA FROM MACHRIHANISH, KINTYRE.

To face p. 137.]

of the upper. The junction is only marked by the lower limit of the phenocrysts. In the present note we are concerned chiefly with number (3) of Kennedy's conditions as we are not dealing with the nature of the field occurrence. Perhaps it should be mentioned at this stage that the writer has no doubt that the rock from which the present slice was cut is a true flow.

Some of Kennedy's conclusions are of special interest to us here. He has proved that the two magmas which gave rise to the porphyritic and non-porphyritic rock types underwent differentiation prior to extrusion and must have existed as separate bodies within the magma basin, becoming available at about the same time. The non-porphyritic member was followed by the porphyritic. In the slide which forms the subject of the present note it can be demonstrated that there are two lavas—not, however, of two easily distinguishable rocks (cf. number (1) of Kennedy's conditions) but of *practically identical rock types.* It is also clear that there is no chilled margin between the two types and in the greater part of the slide it is hardly possible to point to the junction between them. There exists, however, part of a vesicle filled in with magnetite, calcite and silica, undoubtedly formed in one of the lavas as a sphere with concentric layers. However, *before the first lava had cooled, and after the formation of the vesicle, the second lava was extruded over the surface of the first, carrying away more than half of the vesicle, leaving the remainder to tell the story.* The fact that there is no trace of the part broken off indicates considerable movement of the upper over the lower lava. It is here supposed that the flow which contains the vesicle is the lower, and that which cuts off the vesicle is the upper.

It so happens that in the immediate neighbourhood of the vesicle the two lavas are distinguishable by the fact that the upper has marked flow structure indicated by parallel alignment of the felspars. The two rocks are of mugearitic composition.

The lava from which the slice was cut occurs at Uisaed, about half a mile west of Machrihanish village, Kintyre (Sheet 12 of the Geological Survey 1 inch maps).

The writer is indebted to his colleagues in the University of Glasgow and to Mr. W. Q. Kennedy, of H.M. Geological Survey, for discussions on the subject of this note. Mr. Kennedy has also read the original manuscript. The writer was aware of some of the difficulties connected with the infilling of the vesicle in the fluid lava, and Mr. Kennedy again drew attention to them. The writer thinks that the calcite is not an original mineral of the vesicle.

EXPLANATION OF PLATE VIII.

FIG. 1 (× 10) shows faint junction between the two lavas running roughly S.E. from the bottom corner of the vesicle. Fig. 2 shows vesicle much enlarged (× 35). The black is iron oxide, the colourless calcite, and the grey agate-banded material in the centre of the vesicle is pale green cryptocrystalline silica.

REVIEWS.

Diskordanz und Orogenese der Gebirge am Mittelmeer. By Wilfried von Seidlitz. pp. xxiv + 649, with 14 plates and 140 figures in the text. Berlin: Gebrüder Borntraeger, 1931. 75 marks (bound).

Das alpine Europa und sein Rahmen. By L. Kober. pp. 310, with 3 plates and 33 figures in the text. Berlin: Gebrüder Borntraeger, 1931. 20 marks (in paper); 22 marks (bound).

THESE two books deal with the same subject, but their method of approach and their conclusions are different, and the literary styles of the writers are as far apart as those of Dr. Johnson and Dean Swift. Even the beginner in German will have little difficulty in finding Kober's verbs; to read and appreciate von Seidlitz he must wait till he is no longer a beginner.

Von Seidlitz's volume is much the larger of the two. He does not neglect the lessons of the Alps, but that range is only a small part of the great belt of folding which stretches through Southern Europe, and the most intensive study of the Alps alone will never solve the problems presented by the whole. He seeks a new road and approaches from the Mediterranean. The first section of the book deals with general questions which concern the region as a whole, such as the distribution of igneous rocks, the significance of Zwischengebirge, etc. Especially interesting is the chapter on the connection between earthquakes and tectonic structure. There is a remarkable correspondence between some of the conclusions drawn by Sieberg from a study of earthquakes and some of those reached by the author from geological considerations.

The second section, which occupies more than half the book, treats the eastern and western Mediterranean as separate entities, and examines in detail the structure of critical areas, the examination extending beyond the folded belt into both the backland and the foreland. The student whose library is limited will here find much information which is not otherwise accessible to him, and the very useful bibliography will help those who are more fortunately placed. But the main object is always kept in view. The inquirer must not look for stratigraphical details; it is the structural relations that occupy von Seidlitz.

In the last section the author draws a picture of the whole as his researches have led him to see it. It is an interesting picture, but only the slightest sketch can be attempted here. In the west the foreland of the folded belt lies north of it, the Sahara is the backland, and the overthrusting is from south to north. In the east the foreland lies south of the belt, the Russian platform is the backland, and the overthrusting is from north to south. Such movements could not take place without the production of a series of transverse fractures, the eastern flanks of which move southwards relatively to the western flanks. The direction of these fractures is approximately from north-west to south-east. One of the most important lies outside the Ionian Islands, southwards it passes by the greatest deep of the Mediterranean, northwards it lies upon the eastern flank of the Apennines; and the reader's eye will travel of its own accord to the junction of the Eastern and Western Alps.

For the complications which have resulted from the presence of Hercynian relics and from other causes the reader must refer to the book itself. The volume is very well illustrated and is provided with a good bibliography and a full index. Its only faults are its weight and its price. The former is due to the glazed paper required by the illustrations. The latter suggests that Germany has something to learn from us with regard to book production, but perhaps in England no publisher except a University Press would publish such a work at any price, without a guarantee.

Kober's book is less than half the size of the other, but his conciseness enables him to compress a large amount of matter into his pages without any loss of clearness. Like von Seidlitz he has travelled extensively over the area concerned, but his approach to the problems involved is from the Alps. Throughout the folded belt he recognizes the same elements that he sees in the Alps themselves.

According to Kober, though individual ranges may have a front and a back, every orogenic belt considered as a whole has two fronts. There is not a foreland upon one side of it and a backland upon the other, but a foreland upon each, and there is overthrusting towards both. Between the two overthrust bands lies an intermediate zone, the Zwischengebirge, characterized by Basin Range structure rather than by any kind of overthrusting. It varies greatly in width and sometimes diappears altogether so that the two overthrust bands come together. In the orogenic belt that includes the Alps the ranges which look towards Europe belong to the northern overthrust band, those which look towards Africa and Syria belong to the southern band. Kober divides these bands into zones which correspond with the Helvetian, Pennine, and East Alpine systems of the Alps, and traces the whole series of zones from the Straits of Gibraltar to Asia Minor and beyond. We can do no more here than indicate the position of the intermediate or Zwischengebirge zone. In the west it lies beneath the Mediterranean north of Africa and Sicily, it bends northwards between Italy and Sardinia, and disappears in the Alps. East of the Alps it occupies the Hungarian plain, runs through the Balkan peninsula as a comparatively narrow band, and broadens again in Asia Minor between the Taurus and the Pontian ranges.

Those who know any of Kober's books will not need to be told that he explains his views with the greatest clearness. Diagrammatic sections help the reader at every step and the three plates which accompany the volume are a remarkably graphic expression of his general conclusions. These conclusions are very different from those of von Seidlitz, but there are more points of contact than may appear from these brief synopses.

Neither author goes very fully into the ultimate causes of the movements. Kober thinks that however old-fashioned the contraction theory may be, no newer one is better; von Seidlitz prefers a later fashion and favours magmatic currents.

P. L.

SIMPLE DETERMINATIVE MINERALOGY. By H. R. BERINGER. pp. 239. London: Mining Publications, Ltd., 1931. Price 10*s*.

THE preface to this work states that it is "not intended to supersede systematic instruction in the science of mineralogy", but is designed to facilitate the recognition of minerals by students and prospectors. Reliance is placed primarily on determinations of hardness and specific gravity, followed by blowpipe tests. It is on the grounds of its claims to simplification that the book seems most open to criticism. The choice of mineral species to be included has apparently been made by exclusive reliance on Dana's *System* (1892), excluding even the later appendices. As a result, many synonyms and discredited species encumber the pages—limonite and turgite, to give a single example, appear with distinct specific gravities. On the other hand, no summary of characteristics is given for well-marked families, such as the zeolites, the attempt being made to lead straight to each individual species. The formulae are written in terms of oxides, which is certainly the best device for the non-specialist, but here, again, it is a pity that the attempt to simplify should lead to the use of definite proportions in terms of whole numbers for the most obvious solid solutions—zinnwaldite, for example, appears as: $H_2O.2K_2O.2Li_2O.3FeO.4Al_2O_3.F_8.14SiO_2$. The terms, singly oblique and doubly oblique, for monoclinic and triclinic, side by side with the conventional terms for the other systems, strike oddly on the ear of the mineralogist. That a considerable measure of success attends the use of the method in practice may be inferred from the fact that it is the product of many years of teaching, and has been in use at Camborne for ten years. One feels, however, that a simplification on the lines indicated would be a real improvement.

F. C. P.

ELEMENTS OF OPTICAL MINERALOGY. PART I: PRINCIPLES AND METHODS. By A. N. WINCHELL. 4th edition. pp. 12 + 248; 266 text-figures and 4 plates. London: Chapman and Hall, 1931. Price 21*s*. net.

THE third edition (1928) of this work differed from its predecessor in the inclusion of a chapter of 22 pages on the Fedorov Universal Methods and on variation methods of determining refractive indices. In the present edition this chapter has been further expanded, and now includes a description of the Emmons modification of the universal stage. These methods are undoubtedly destined to play an important part in determinative mineralogy, and their development is at present chiefly hampered by the costly nature of the necessary apparatus. Part I of this composite work remains a book one can strongly recommend to the beginner (in contradistinction to the remaining parts, which are essentially for the researcher). The price has unfortunately been increased.

F. C. P.

THE BALTIC REGION. By E. G. WOODS. pp. xv + 434, with 143 figures. London, Methuen and Co., Ltd. Price, 18*s*.

THE aim of this book is ostensibly geographical, but it cannot fail to receive also a warm welcome from geologists. The author is eminently well fitted for her task, as she possesses not only an intimate acquaintance with the geography and geology of the region dealt with, but also an unusual knowledge of the Scandinavian and other languages. This has enabled her to wade through the enormous literature of the subject, and the resulting clearly written summaries of the geology, especially those of the Pre-Cambrian and the Pleistocene, will be of immense service to students, from whom so much of the recent work has been concealed by linguistic difficulties. So far as the reviewer is aware, Scandinavian work on the glaciation of the Baltic region has never been summarized in English since the appearance of Wright's *Quaternary Ice Age*, an admirable work, but now some twenty years old. Since that date there have been innumerable further publications on the subject, the gist of which is here brought together in an easily accessible form. There is also a very extensive bibliography.

The more purely geographical sections also afford delightful reading, and the book is much embellished by the charming sketches by Miss K. C. Thomson. Many of these are in fact far more instructive than the everlasting geological photographs on heavy, shiny paper that everybody is so tired of.

CORRESPONDENCE.

PROFESSOR VON BUBNOFF'S *GRUNDPROBLEME DER GEOLOGIE.*

SIR,—In reference to your review of Professor S. von Bubnoff's book, *Grundprobleme der Geologie* (pp. 522–3, GEOLOGICAL MAGAZINE, Nov.), and the opinion therein expressed that this excellent work should be translated into English, I may say that a translation by me has been in progress for some time, and will be published as early as possible next year.

G. W. TYRRELL.

THE UNIVERSITY,
GLASGOW.
19th November, 1931.

THE GENETIC RELATIONSHIPS OF PEGMATITES, APLITES AND TIN VEINS.

SIR,—Under the above heading, in your issue of October, 1931, Dr. Derry, in discussing the distinction in texture between pegmatites and aplites, considers that during crystallization most of the water present in the magma follows one differentiate and forsakes the other, and he asks what is the cause. His comment, that "the study of physical chemistry fails to reveal reasons for a sharp separation of this sort", does not do justice to theoretical chemistry, for that branch of science offers, in the form of the Distribution Laws, a very sound basis of explanation of the apportionment of constituents (solutes) of the magma, including the minor and often economically valuable ones, between the various differentiation products (phases) as well as their persistence in the same.

Operation of those laws attends equilibrium tendency, and completeness or otherwise of the division of both solvent and solutes at their behest may be taken as some indication of how nearly equilibrium was attained. The distribution laws offer, for example, a facile explanation for the very wide (but usually uneconomic) distribution of gold in the Keewatin rocks, and their Algoman intrusives, of Northern Ontario.

H. C. BOYDELL.

TORONTO,
ONTARIO.
13th February, 1932.

THE TERM "ARVONIAN".

SIR,—While sorting some old papers, I have come upon the letters which I received in reference to this question, in response to my suggestion of June, 1930, in this Magazine.

Only four persons wrote. Of these, two expressed strong approbation, and hoped that the term would be adopted. One writer suggested, but afterwards withdrew, "Padarnian." The fourth thought there might be confusion between "Arvonian" and "Avonian".

In June, 1930, I concluded my letter by saying that "if serious disapproval be not manifested, then I will adopt 'Arvonian'". In view of these four letters, and of the silence of everybody else, it is clear that there is no serious disapproval. I feel therefore free to adopt the term.

Edward Greenly.

THE PLEISTOCENE SUCCESSION IN ENGLAND.

Sir,—In his paper on the Pleistocene Succession in the January number of the Geological Magazine, Dr. K. S. Sandford has made a notable contribution towards the solution of our difficulties in the correlation of glacial and interglacial episodes with the industrial phases of Early Man.

I agree with the broad outlines of his correlation—indeed, I had independently been led to practically the same conclusions, though our approach to the problems was rather different. By reversing the "apparent" order (in his *Q.J.G.S.* paper) of the Summertown–Radley Terraces and Wolvercote Channel, by correlating the Plateau Drift with the Norwich Brickearth (containing Scandinavian erratics) and abandoning any correlation with the Cromer Forest-bed, Dr. Sandford has cleared up most of the difficulties I foresaw.

As I shall be attempting a general conspectus of the problems a little later in the year, I will only point out at this stage a slip in Dr. Sandford's summary table on p. 15, which may confuse readers, because it involves an apparent contradiction with other parts of the paper. The Brown Boulder Clay of Hunstanton finds its equivalent in Yorkshire in the Hessle Boulder Clay, and in the Thames Valley in the Ponder's End stage. The Upper Chalky Drift of East Anglia and the Coombe Rock appear to be represented in Yorkshire by the Upper Purple Boulder Clay, which it appears must be attributed to an ice-advance separate from that of the Lower Purple Boulder Clay. The view of a four-fold glaciation of Yorkshire has the support of Drs. Raistrick, Trotter and Hollingworth, to whom I offer my thanks for their trouble in furnishing me with their detailed correlations.

P. G. H. Boswell.

DISTURBED GLACIAL BEDS IN DENMARK.

Sir,—In a recent publication of the Geological Survey of Denmark, the famous sections of disturbed glacial beds at Lønstrup have been described and admirably illustrated by Mr. Axel Jessen. British geologists will welcome this detailed description of a classic area, and will note with some interest that the disturbances, formerly regarded by our Danish colleagues as the result of post-glacial earth-movements, are now attributed to the work of ice. Certain references to my own investigations at Lønstrup in 1925 (published in the *Trans. Roy. Soc. Edinburgh,* lv, 1927) involve, however, mis-statements which should be corrected. That I have no wish to indulge in profitless controversy will, I think, have been evident from the fact that I refrained from replying to the attack launched upon me by Mr. Hintze in the *Medd. Dansk. Geol. Foren.* in 1928. As nearly the whole of Mr. Hintze's paper was devoted to personalities, and as he reasserted his opinion that the Møen disturbances were not of glacial origin, I was content to let the scientific world judge between us.

In the recently-published memoir, however, are statements which impugn my good faith. Mr. Jessen says of me " he has taken advantage of my readiness to help and my trust in him to hastily publish the above paper on Lønstrup Klint ". I would here repeat the acknowledgements I have previously made of Mr. Jessen's kindness to me during my visit to Denmark. But instead of desiring to take advantage of him by hastily publishing my work, I would say that I took much trouble to consult my Danish colleagues. Far from objecting to the publication of my views, Dr. Madsen, as Director of the Survey, wrote in April, 1926, to say that he had read the MS. of my paper with the greatest interest, and that he had tried unsuccessfuly to secure funds for its publication in Denmark, but intended to make another attempt. Again, in May, 1926, Dr. Madsen stated that he could not get the paper printed in Denmark, but that I ought to publish it in England. No objection was raised by Dr. Madsen on the grounds that I should be anticipating Danish work.

Mr. Jessen further says : " Mr. Slater seems to have been content to walk down to the beach and draw a sketch of the cliff ; but as he has obviously not taken a single measurement, neither of height nor lengths nor of the dip or direction of the strata or the overthrust planes . . ." Far from this being the case, after parting with Mr. Jessen I spent a fortnight in systematically measuring the section as detailed in my paper, and plotting the section to a scale of 1 in 1,200. A comparison of Plate I of my paper with Mr. Jessen's section (1931) at once shows that I have reproduced much more measured detail than he has done.

I leave the matter there, for I am now well satisfied that the Danish Geological Survey agrees so far with me that the disturbances are of *glacial* origin, and not tectonic as they formerly thought, even although we may differ as to the exact *modus operandi.*

GEORGE SLATER.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY,
SOUTH KENSINGTON.
8th February, 1932.